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Editors

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Editors
Carlos Coelho
Civil Engineering Department
University of Aveiro
Aveiro, Portugal

Caroline Hallin
Water Resources Engineering
Lund University
Lund, Sweden

Francisco Sancho
Hydraulics and Environment Department
National Laboratory for Civil Engineering
Lisbon, Portugal

Paulo A. Silva
Physics Department
University of Aveiro
Aveiro, Portugal

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Sensing Short-Term Adaptive Cycles in Mesotidal Energetic Beaches from Satellite Imagery

Susana Costas[1](✉), Jacqueline Santos[1], Yarran Doherty[2], Kristen D. Splinter[2], Luisa Bon de Sousa[1], Katerina Kombiadou[1], Theocharis Plomaritis[3], and Rui Taborda[4]

[1] CIMA/ARNET, University of Algarve, Faro, Portugal
scotero@ualg.pt
[2] UNSW Water Research Laboratory, UNSW, Sydney, Australia
[3] INMAR/Applied Physics, University of Cadiz, Cadiz, Spain
[4] IDL/FCUL, University of Lisbon, Lisbon, Portugal

Abstract. The rapid development of approaches to automatically detect and extract shorelines from satellite imagery is revolutionizing the way we study coastal systems, offering deeper insights into their dynamic responses and adaptive capacities. This study evaluates the performance of the CoastSat toolkit in detecting shoreline retreat and recovery at Praia de Faro beach, South Portugal, following storm Emma in March 2018. The mesotidal, low-tide-terrace beach experienced significant erosion, with an average retreat of 20 m. PlanetScope imagery is used to assess shoreline detection accuracy, due to its higher temporal coverage compared to other open-access satellite constellations. This includes understanding the correspondence between the detected waterline and two water levels: the tide level and the instantaneous water level (combined effect of wave runup and tide). Linear water level corrections are applied to horizontally translate the detected water levels to a reference elevation that enables temporal comparisons. Results suggest that beach morphology strongly influences optimal correction approaches due to the type of beach response to storms, such as profile rotation. Under non-storm conditions, detected waterlines generally represent astronomic tide levels. While tide-level-based corrections improve accuracy during storms, runup-based corrections consistently outperform under non-storm conditions. Consequently, applying corrections that account for slope changes, runup levels during non-storm conditions, and tide level under storms enables the detection of storm impacts and recovery with an accuracy of approximately 6 m in Praia de Faro. These findings highlight the importance of tailoring detection methodologies to the morphological state of the beach as it evolves over time.

Keywords: Shoreline detection · Storms · Morphological state

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1 Introduction

There is growing consensus on the understanding that resilient coasts are not necessarily stable, but dynamic and adaptive systems changing in response to external disturbances [1]. Especially under increasing future uncertainty and changing conditions, system resilience needs to be assessed by approaches centered on evolution and adaptation [1]. The increasing availability, resolution and spatial coverage of satellite imagery opens new means of deriving reliable, continuous and long-term data in the coastal zone, enabling the reconstruction of adaptive cycles at temporal scales ranging from months to decades. Yet, the application of these data depends on their accuracy and temporal frequency. Accuracy limitations are usually linked to the definition of the shoreline and the ability to identify the desired transition [2], and to the correction of the extracted shorelines, especially as tidal range increases [3]. Strategies to improve the accuracy of results include not only tidal corrections but also, but also, and depending on the beach state [4], runup, swash or surge levels [4, 5].

Here, we explore automated shoreline detection from satellite imagery, focusing on its performance under the impact of storms. This exercise is intended to assess short-term beach profile adaption cycles at the mesotidal, energetic coast of South Portugal, namely at the (intermediate) low-tide-terrace (LTT) beach of Praia de Faro. Shoreline retreat induced by storm Emma reached values around 20 m while recovery profiles recovered up to 91.7% of the eroded volume after two months [6]. The magnitude of the observed retreat and the rapid recovery, offer a challenging example in terms of beach morphodynamics to test the accuracy and sensing ability of satellite-derived shorelines.

2 Approach

The present work applies the open-source python-based CoastSat toolkit [7, 8] for the detection of satellite-derived shorelines (SDS), to explore shoreline changes associated with the impact of the Emma storm (28 February to 5 March 2018) in Praia de Faro (Fig. 1). The lower revisit period of PlanetScope (PS), compared to Landsat 7 and 8 and Sentinel-2, leads to higher availability of imagery with low to none cloud coverage (41 versus 5, 4 and 12, respectively) around the storm. Due to the high temporal coverage of PS, the analysis uses PS imagery obtained between 3 February and 28 April.

First, we evaluate the effect that extraction parameters related to the thresholding techniques have on the extracted satellite derived waterlines (SDWLs), by evaluating the correspondence between the SDWL and two water levels: (1) the tide water level, accounting for surge and astronomic tides, and (2) the instantaneous water level, accounting for wave runup. The first was obtained from the Huelva tidal gauge (Redmar network, Puertos del Estado) and the second was calculated [9] using wave time-series from Faro buoy (Fig. 1). The transition or threshold value that separates water and sand is computed applying the weighted peaks (WP) thresholding approach [8]. The sensitivity of the shoreline detection to the constant parameter (peak fraction) is evaluated by extracting five datasets using peak fraction (pk) values ranging between 0.6 and 0.8.

Then, we examine the possible influence of the beach morphology to the horizontal correction of extracted SDWL to a common elevation contour to enable temporal comparison of SDS. For the case of Praia de Faro, this level corresponds to the top of the beach berm, which is around 3 m above mean sea level (MSL). Three beach profiles from RTK-DGPS surveys before and after the storm are used to assess the accuracy of the SDS (profile PW, PC and PE; location Fig. 1). One of the profiles (PE) is backed by a foredune while the other two have rip rap seawalls (PC and PW).

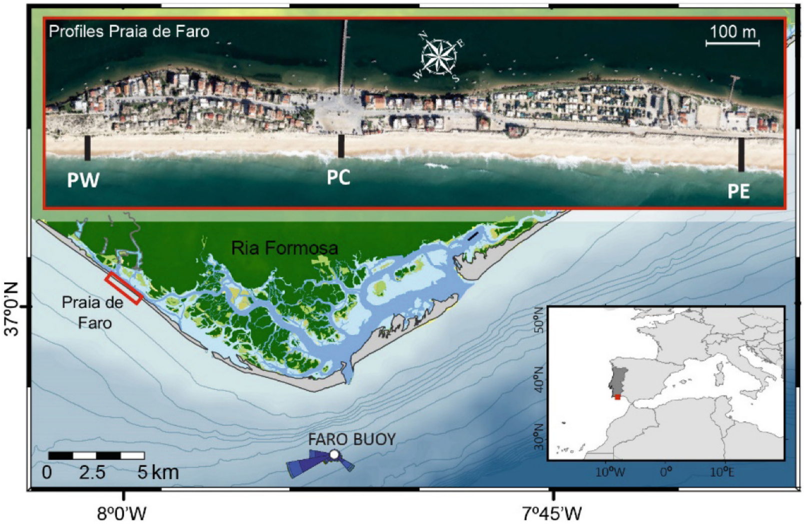

Fig. 1. Location of the study area and in situ measured profiles.

3 Results

3.1 Satellite Derived Waterlines and Water Levels

Five sets of SDWL were extracted from PS imagery using a range of pk values (0.6 to 0.8 with a step of 0.05). The greater the pk value, the landward the position of the SDWL. This difference increases during low tide and storm conditions, reaching values of 20 m between the two extreme values. Examining the position of these lines with the corresponding images, one can observe that the indicator detected is the transition between the wet and the dry sand or the water if the image coincides with the upwards excursions of the swash. The wet sand seems associated with water saturation when the tide is low and the LTT is exposed or with the latest swash/runup excursion across the beachface. Therefore, the landward-most line appears to better represent the wet/dry transition, especially when tides are low. The elevation in the measured profiles, corresponding to the horizontal position of the SDWL, was extracted in order to compare with tide and runup levels. The results do not show a clear correspondence between the water levels and the projected elevations, with the latter systematically corresponding to levels greater than the tides and lower than the estimated runup. The estimated RMSE values are approximately 1 m for both tide and runup levels (Table 1). Errors decrease for tide levels as pk values are reduced (e.g., pk = 0.6, RMSE = 0.68 m) but increase for runup levels, reaching 1.37 m. Bias values are also around 1 m, with the tide consistently showing a negative bias and the runup showing a positive one. These results suggest that the level captured by the SDWL may correspond to the tide level, which is more accurately represented when pk = 0.6.

Table 1. Accuracy results (meters) for the extraction and correction of shorelines. Comparison between the elevations of the SDWL in the profiles and the tide and runup levels in the first row.

		pk = 0.6 tide	pk = 0.6 runup	pk = 0.8 tide	pk = 0.8 runup
SDWL height & WL	RMSE (Bias) All profiles	0.7 (−0.3)	1.4 (1.2)	1.1 (−0.9)	1.1 (0.7)
Constant slope	RMSE (Bias) All profiles	18.1 (−9.3)	24.0 (−19.5)	16.18 (2.3)	20.5 (13.7)
Variable slope	RMSE (Bias) All profiles	7.9 (0.9)	16.6 (−13.7)	9.2 (−7.7)	12.9 (7.4)
Constant slope	RMSE (Bias) Non-storm	10.5 (−3.3)	15.2 (−12.5)	8.3 (−4.8)	7.1 (4.9)
Variable slope	RMSE (Bias) Non-storm	8.3 (−0.1)	11.6 (−8.5)	9.7 (−8.3)	4.7 (2.2)

3.2 Satellite Derived Shorelines

Corrected shorelines were obtained by projecting the SDWL to the 3 m contour above MSL, which reflects volumetric changes across the profile for the study area. RMSE values indicate poor performance when the correction assumes a constant beachface slope (Table 1) and slight improvements for pk = 0.8. Accuracy significantly improves when observed beachface slope variations are incorporated, reducing errors to below 10 m for the tide level corrections. Notably, better fits are achieved for non-storm conditions, highlighting the challenges of correcting for storm conditions. Excluding storm conditions reduces RMSE to approximately 5 m when applying pk = 0.8, variable slope and runup-based corrections.

A final analysis suggests that greater accuracy is achieved when corrections are tailored for each profile. For profile PE, tide-based corrections with pk = 0.8 provide the best fit before and during the storm, whereas runup-based corrections perform better immediately after the storm passage. For profiles PC and PW, runup-based corrections yield better results, except during the storm. Incorporating these specific adjustments can improve the overall RMSE to 4.6 m (pk = 0.8). While this demonstrates the potential for increased accuracy, applying such tailored corrections to long-term datasets may not be practical due to uncertainties beyond the validation data. Consequently, we found that using runup levels to correct shoreline positions under non-storm conditions and tide levels during storm conditions across all profiles slightly reduces accuracy but provides an acceptable result, with an RMSE of 5.7 m. Applying the correction criteria to the three-month SDWL dataset yields promising results, effectively capturing the storm-induced retreat and recovery, with relatively stable SDS observed before and after the storm passage (Fig. 2). Still, the profiles backed by hard structures (PC and PW) show higher error with in-situ measurements than the natural profile (PE).

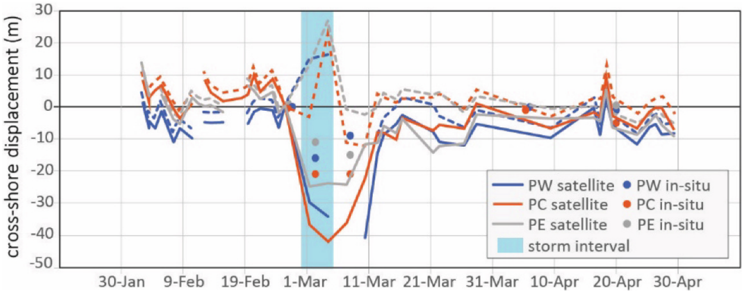

Fig. 2. Time-series of cross-shore changes. Dashed lines show the results for constant slope.

4 Discussion

This work evaluated the potential of different satellite platforms to capture storm erosion and recovery at a mesotidal intermediate LTT beach in southern Portugal. The greater temporal frequency of PS compared to Landsat 7 and 8 and Sentinel-2 made it a highly reliable source of data for the storm impact evaluation in the area. The application of different thresholds to separate water from sand during SDWL extraction from Coastsat [8] helped to identify the best solution for the study area. The results indicate that the detected SDWLs represent the tide level, improving with thresholds that push the lines towards the water (i.e., low peak fraction). However, when shoreline position corrections are applied under non-storm conditions, runup-based correction and thresholds shifting the lines landward, retrieve better accuracies. Alternatively, tide-based corrections perform better during storm conditions. One question arising from these results is the discrepancy between the water level identified by the satellite and the level that performs better for horizontal correction. This becomes more pronounced during low tides when the LTT is exposed, suggesting that uncertainties may stem from the average slopes used for correction, which do not represent the profile complexity. However, testing this hypothesis is not possible with the available data, as the profiles do not extend to the entire LTT morphology. In general, we find that accuracies improve if the changes in slope are considered and that uncertainties might be derived from the complex LTT beach morphology, where two contrasting slopes define the upper and lower intertidal zone of the profile. The observed storm-induced erosion in the study area flattened the profile, inducing profile rotation and pushing the detection lines seaward because of the storm impact. Thus, if the slope is not considered, the results give the opposite response with enlargement of the beach under storm impact and the transfer of sand to the lower part of the profile. Previous works found that alternative water level definitions for horizontal correction of shorelines might be required, depending on the beach morphologic state [4]. The authors found that tidal elevation led to substantial accuracy at reflective beaches, while accounting for wave-induced water fluctuations performed better in dissipative sites. Other works found that accounting for the changes in slope did not improve accuracies [10]. The discrepancy between this statement and our findings can most likely be attributed to the two distinct types of beach response of flattening and retreat [11]. Flattening requires approaches that incorporate slope changes to account for profile rotation, whereas under retreat quasi-stable slope can be assumed.

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Risk Communication by Coastal Geoscientists

Ana Matias[1](✉), Bruno Pinto[2], A. Rita Carrasco[1], and Neide Areia[3]

[1] CIMA/ARNET - University of Algarve, Faro, Portugal
ammatias@ualg.pt
[2] MARE/ARNET - University of Lisbon, Lisbon, Portugal
[3] CES - University of Coimbra, Coimbra, Portugal

Abstract. Storms often harm coastal communities, a situation expected to worsen due to climate change and urban development. Effectively communicating with diverse audiences is thus critical for adapting to and attenuating increased coastal risks. This research focuses on risk communication by Coastal Geoscientists and Engineers, aiming to assess their perspectives and practices. The method used was an online questionnaire, with data collected in 2022–2023. The sample (n = 133) average age was 45, with slightly more men and mostly from Europe. About 95% of participants reported engaging in public communication, and most do coastal risk communication. Direct interaction with audiences such as public talks (74%) is preferred over indirect communication, and 79% had at least one annual contact with a journalist. Participants believe decision-makers should be more informed about risk location, frequency of occurrence, and how to engage citizens with coastal risk. However, this does not align with their top communication subject (coastal physical processes). Some significant differences were found in how gender, professional roles, and scientific backgrounds influence perceptions and priorities in coastal risk communication.

Keywords: Science Communication · Geoscience outreach · Coastal Risk · Engagement with society

1 Introduction

Storms on coastal areas often damage urban shorelines, placing coastal communities at immediate risk. In 2020, 2.15 billion people lived in the near-coastal zone and 898 million in the low-elevation coastal zone globally [1]. Consequently, significant areas, infrastructures and people are at risk from coastal hazards including storm surges, inundations, waves, and coastal erosion. Furthermore, the coastal risk is likely to increase in the future due to climate change and ongoing coastal development [1, 2]. Hence, scientific and management organizations bear ethical obligations to provide useful information about the risks people face when benefiting from being in coastal areas.

Communicating with diverse audiences is critical for adaptation to, and mitigation of increasing coastal risks and developing plans for integrated coastal management [3]. Though studies have been addressing the complexity and putting forward best practices in risk communication (e.g., [4]), there is still a lack of tailored science communication

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strategies efficient at engaging citizens in coastal risk and thus augmenting the success of the coastal adaptation processes [5].

Communication of coastal risks, as with all other scientific areas, relies on the joint efforts of several professional groups (including scientists, science communicators, journalists, policy-community mediators, and decision-makers). The current research is focused on an informal scientific field - Coastal Geoscience and Engineering (CGE). CGE, defined by [6], encompasses professionals working on coastal processes, integrating expertise across physics, geomorphology, engineering, and management. CGE has many topics suitable for public engagement with science, such as the impact of storms, tidal currents, coastal management, coastal evolution, sea-level rise, ecosystem services, and climate change.

The main objectives of this research were to have an international depiction of science communication done by CGE, identify their perspectives for communication, and assess what they think and how they do risk communication.

2 Methods and Sample

The method to collect data was a self-administered online questionnaire with 25 closed questions, taking an average of 10 min to complete. A comprehensive description of data collection and analysis can be found in [7]. Experts' names were extracted from three major international conferences: Coastal Sediments 2019, Coastal Engineering 2020, and Coastal Dynamics 2021. Data was collected between September 2022 and March 2023. Of the 975 contacts extracted from the proceedings, 133 responses were obtained (14% response rate).

Most respondents were male ($n = 71$, 53.4%), with a mean age of 45.4 ($SD = 11.2$). The sample average age was 45 and closely balanced between Natural Sciences (51%) and Engineering. Main participants' career status were researchers ($n = 57$, 42.9%), Assistant/Associate Professors ($n = 22$, 16.5%) and Full Professors ($n = 19$, 14.3%). Most participants were from the European continent ($n = 95$, 71.4%), even though North America and Oceania had over 10 replies in each case.

Experts' perceptions and attitudes towards science communication, reported practices and opinions about coastal risk communication were assessed using descriptive statistics. Mann-Whitney U tests were conducted to find potential differences according to sociodemographic characteristics (gender, professional category, and scientific background). In the case of gender, the analyses exclusively focused on male and female participants due to the limited representation (3.8%, $n = 5$) of other genders (e.g., non-binary).

3 Results and Discussion

3.1 Perspectives and Practices of Science Communication

Only 5% of respondents to the survey said they do not communicate with a lay audience. In other studies, the percentage of researchers who do not communicate is higher, as reported by [8] regarding geoscientists (24%); [9] regarding Portuguese geoscientists

(11.5%); [10] concerning USA climate scientists (27%); and [11] on UK scientists (26%). Most CGE participants (79%) consider science communication as part of their job. Nevertheless, they identified barriers to these activities, the most frequent was the lack of time due to other obligations (as recorded by [9, 11]). Direct interaction with audiences is preferred (e.g., lectures, talks, 74%), over indirect ways of communication (media and social media). The public sector (e.g., municipalities, 55%) and school students (43%) were the main audiences. About 79% had at least one contact per year with a journalist, a value comparable to results obtained by other studies [10, 12]. For most aspects of science communication, differences in opinion according to gender, age, and professional category were not significant. However, it was found that more women perceived the lack of communication training as an obstacle, and had a greater tendency towards hands-on activities. The interaction with journalists was significantly more frequent among men, professors, and older individuals.

3.2 Risk Communication

The majority (82%) of participants engaged in coastal risk communication, focusing on the type of coastal hazards (59%), such as severe storms and sea-level rise (Fig. 1).

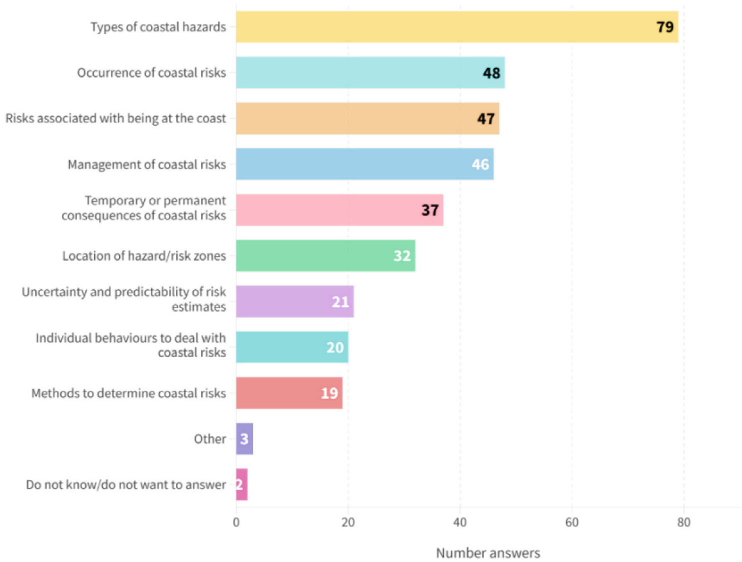

Fig. 1. Prevalence of participants' responses regarding coastal risk topics for communication. Note that multiple answers were allowed, therefore the sum is greater than 100%.

The least relevant topic was the methods to determine coastal risks (48%). Notably, 30% considered that individual behaviours in dealing with coastal risks are a less relevant topic for communication (Fig. 1). Men and women generally share similar perceptions and attitudes toward coastal risk communication, however, women more frequently signed the importance of communicating individual behaviours to deal with coastal risks.

Professors were marginally more likely to prioritise the description of 'Types of coastal hazards', as a primary topic for communication. On the other hand, researchers more frequently identified the risks associated with being at the coast, as a primary focus, a difference that reached statistical significance. Experts with an engineering background showed a greater emphasis on technical aspects of coastal risks. For example, they more frequently identified the 'Occurrence of coastal risks' as a main topic, with a marginally significant difference. Furthermore, 'Methods to determine coastal risks' were prioritised significantly more often by engineering experts. These findings suggest that scientific background significantly influences experts' priorities and attitudes toward coastal risk communication.

Participants think decision-makers should be more informed about risk location, the frequency of occurrence, and how to engage citizens with risk (Fig. 2). However, this does not align with the participants' top communication subject to decision-makers, which were the physical processes of coastal risks.

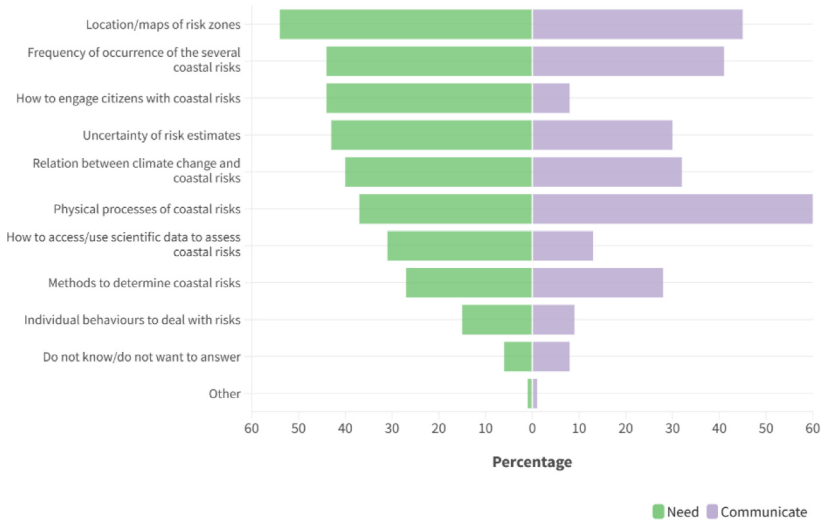

Fig. 2. Topics of coastal risk that researchers think decision-makers should know more about (left-hand side, green) and that researchers have communicated (right-hand side, violet).

The analysis of gender in experts' perceptions revealed no statistically significant differences. Notable differences emerged between researchers and professors in their perceptions of decision-makers' informational needs. Researchers prioritised 'Location/maps of risk zones', while professors 'Uncertainty of risk estimates'. Regarding communicated topics with decision-makers, professors were more likely to have addressed 'Methods to determine coastal risks' and the 'Relation between climate change and coastal risks'. These findings suggest that professors focus on methodological and contextual aspects of coastal risks, while researchers highlight spatial and participatory elements, reflecting a local approach. Experts from the natural sciences were more likely to prioritise 'Location/maps of risk zones' as a critical need for decision-makers, though this difference was marginally significant. Conversely, engineers reported more frequent communication about the 'Uncertainty of risk estimates'. This significant discrepancy indicates that engineering experts place greater emphasis on addressing uncertainties in risk assessments, while natural sciences experts prioritise spatial information.

4 Conclusions

This study shows that 73% of the inquired researchers on coastal geoscience and engineering have been active in science communication for at least 1/year. Even considering that more productive researchers may communicate more [10] and that the sample is biased towards the more productive researchers, it is reasonable to conclude that CGE researchers are considerably active in science communication. Topics that are communicated, including risk assessment and impacts of climate change, are mainly tangible issues rather than more abstract science concepts. The findings suggest that the scientists involved in coastal risk are open and willing to communicate, and intend to engage with society and help citizens make informed decisions.

Overall, some significant differences were found in how gender, professional roles, and scientific backgrounds influence perceptions and priorities in coastal risk communication. Understanding these differences is essential for developing interdisciplinary and effective coastal risk communication strategies.

The study may have limitations concerning the sample size and representativeness of the community of coastal geoscientists and engineers. The number of participants was lower than desired and it is possible that the sample is not representative of the community.

The insights stress the importance of considering diverse perspectives in developing tailored and effective communication strategies for coastal risk management. Since there is little previous information about the public communication of coastal geoscientists and engineers, further studies should be done, if possible with a higher number of respondents, to enhance knowledge about this important and increasingly relevant area of science communication.

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