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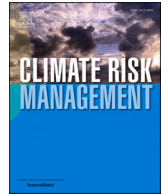
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Communicating the risk of erosion: the effects of map-based communication on risk perception and affect

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ABSTRACT

This study firstly aims to understand the impacts of map representations of coastal erosion on risk perception and affects of lay citizens. Secondly, it aims to study the effect of differing design of cartographic features on observation and interpretation of the message conveyed by different maps. Seven maps were presented to the participants (N = 50), varying according endogenous (abstraction, regalian cartridge) and exogenous characteristics (background, colours). A questionnaire interrogated risk perception and affect before and after observation, while eye-tracking data were recorded during the observation of each map. This experiment shows that communicating erosion risk by maps reduces perceived knowledge of risk but also reduces fear of the risk. The abstraction level significantly impacts observation patterns: correlation maps seem to guide visual attention in a more relevant way and to convey the message more clearly and effectively than other types of maps. But there is no influence of the other characteristics even if interviews show that colours seem to influence the message interpretation.

1. Introduction

Climate change is increasing the frequency and intensity of natural disasters and causing sea levels to rise, making coastal areas even more vulnerable. In this context, it is essential to communicate environmental risks effectively to coastal communities to help them adapt. Cartography is a method sometimes used to communicate those risks. Its strong spatio-temporal component makes it an excellent medium (Dransch et al., 2010), but this type of tool must do more than simply convey information; it must also foster the capacity for adaptation, empowerment and commitment among populations at risk.

Map-based communication in the context of risk prevention has already been studied in relation to flood risk (e.g. Fuchs et al., 2009), or health risks (e.g. Mills and Curtis, 2008), but no study to our knowledge has investigated it in relation to coastal erosion risk.

1.1. Psychological processes involved in risk perception

The concept of risk perception enables us to appreciate the role of both cognitive (Tversky and Kahneman, 1982) and affective

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processes and heuristics (Finucane et al., 2000; Slovic et al., 1991, 2004) in the way laypeople evaluate risks. The hypothesis of a dual process of information processing proposes two interdependent parallel systems (Finucane and Holup, 2006; Van Der Linden, 2014): an analytical cognitive process (Chauvin, 2014) consisting of intentional processing based on formal logic, being slow and costly, and a “risk as feelings” mode (Loewenstein et al., 2001) based on affect, automatic and therefore faster. In the context of risk communication, the impact of affect on risk perception and behaviour has been used extensively through the appeal to fear, aimed at influencing individuals’ decisions by means of frightening messages. But this strategy can be counter-productive if the message doesn’t also integrate elements increasing the feeling of efficacy in the face of risk (Blondé and Girandola, 2016). Thus, risk communication needs to consider both affect and risk perception in order to intervene effectively (Van Der Linden, 2014). The psychometric paradigm (Fischhoff et al., 1978) also incorporates social values taking into account fearfulness of the risk, its unfamiliarity, and the number of people exposed (Slovic, 1987).

1.2. Risk communication through cartographic representation

A common communication tool for environmental risks is cartographic representation, which benefits from *vividness* (Dransch et al., 2010). Indeed, information is concrete and easy to extract thanks to visual salience of cartographic elements, i.e. their quality of being easily and quickly spotted (Fabrikant et al., 2010). This facilitates mental representation and memorization, and since risk representations are associated with anticipatory emotions, vividness also influences the emotional reactions associated with the information presented (Loewenstein et al., 2001), especially for lay populations (Dransch et al., 2010).

There are different types of map, depending on the complexity of the geographic information conveyed and the audience to which they are addressed (Quodverte, 1997). They can vary according to their level of abstraction, i.e. the “simplification of the perception of the real world” (Hoarau, 2015, p.63). Quodverte’s (1997) typology classifies maps in 3 types: analysis maps which present a single theme, correlation maps which are more complex and present several themes, and synthesis maps which combine several themes according to spatial analysis procedures. So, the possibilities for representing information are varied, but how are they received by the public? Fischhoff et al. (1978), in their development of the psychometric paradigm, already referred to the importance of adapting communication to the audience, given the variation in risk perception according to level of expertise, and even other socio-demographic characteristics. Studies on risk communication using maps have long focused on communication aimed at experts and scientists (Mills and Curtis, 2008). However, more recent studies have focused on communicating risk to the non-expert population, notably on the impacts of visual representations of uncertainty (Kübler et al., 2019; Cheong et al., 2016; Ruginski et al., 2016) and on the impact of this type of material on behavioural responses such as the purchase of a house (Kübler et al., 2019) or the intention of protective behaviour in emergency situations (Ash et al., 2014).

1.3. Visual attention and map communication

Map-based communication relies on visual attention, i.e. “the set of mechanisms that enable us to select part of the visual information in order to process it as a priority and correctly orient our behaviour” (Ibos, 2009, p.16). Bottom-up attentional process is an automatic, rapid and involuntary process (Borji and Itti, 2013) influenced by exogenous factors (relating to the physical characteristics of the object) involving visual salience of elements (e.g. size (Francolini and Egeth, 1980), colour (Lohse, 1997), location (Chandon et al., 2009)), and is favoured by the absence of instructions, goals or expertise. The top-down process is voluntary and depends on the object’s semantics and incongruence with the context instead of its visual salience (Loftus and Mackworth, 1978). Even if results remain divergent as to the influence of incongruence on visual salience (Brockmole and Henderson, 2008; Underwood and Foulsham, 2006), cognitive-guidance models has then proposed that attention is guided by person- and sense-specific factors, based on “cognitive representations that are activated or retrieved by the identification, memory and semantic systems from physical data of the scene, as well as from the prior and general state of the cognitive system”. Three essential endogenous factors (relating to the individual and/or the context) therefore impact gaze orientation: the context or “gist”, the objective or task (Hayhoe and Ballard, 2005), and memory, both semantic and episodic (Henderson et al., 2009).

Bottom-up and top-down orientations can be called upon in the same task (Itti and Koch, 2001): top-down processes can be carried out voluntarily and therefore called upon or inhibited and therefore supplanted by bottom-up processes (Muller and Rabbitt, 1989). Finally, visual attention is often approached in studies through the medium of “visual scenes”, or “natural” images, i.e. “visual scenes as a human eye usually encounters them” (Jégou and Deblonde, 2012, p.20). But less studies, to our knowledge, interrogate visual attention processes in map reading. The question therefore arises as to how the characteristics of risk maps guide visual attention and influence their observation and interpretation.

Eye-tracking is ideal for studying visual attention, as it enables the precise recording of an individual’s eye movements and successive fixation points. The pupil is detected and tracked thanks to an algorithm that matches this information to the image the individual is observing, and thus accurately determines where the gaze is directed. It thus enables implicit, objective and precise measurement of how individuals observe a visual stimulus. The characteristics of fixations (location, duration) can inform about the allocation of attentional resources and/or the difficulty of analysing the stimulus (Eckstein et al., 2017). More specifically, fixations correspond to time intervals during which the gaze remains on a very small area, between 0.7 and 1.3° (Bignaut, 2009), as it is never totally fixed. The time interval between fixations depends on the task performed (longer fixations in scene observation than in reading, for example (Rayner, 1998, 2009)) and varies from study to study.

The effectiveness of maps has been studied for many years using eye-tracking measurements (Fuchs et al., 2009; Spachinger et al., 2008). In the 1970s, Dobson (1979) studied visual exploration of maps, and Chang et al. (1985) subsequently demonstrated the

importance of map reading experience in reading and extracting cartographic information. More recently, Meyer and colleagues (2012) proposed concrete recommendations (e.g., symbol visualization, legend construction, etc.) for the design of flood risk maps intended for the general public, based on a method combining participatory processes and eye tracking. However, few studies combine both an eye-tracking approach to information processing and an approach in terms of risk perception (Humair-Charriere, 2018). Furthermore, many of these studies focus on disaster risks (floods, tornadoes, etc.), but to our knowledge, none have yet focused on erosion risk. We therefore question how map-based communication of erosion risk can influence the perception of long-term coastal erosion risk, and how best to represent this risk using different designs.

2. Objectives and hypotheses

The first objective of the study is to determine the effects of map communication on risk perception and affect. Given the vividness of risk communication by map, particularly among the lay public (Weidenmann, 1988, cited by Dransch et al., 2010), we hypothesize that observation of coastal erosion risk maps by non-expert citizens promotes risk perception (H1). We also hypothesize that this observation generates affective reactions by increasing negative affects (H2) and decreasing positive affects (H3).

The second objective is to determine the influence of cartographic features on the observation and interpretation of the message conveyed. Given the influence of exogenous factors, we hypothesize that:

- Map colours influence the distribution of gaze on maps (H4), as well as the transmission of the message conveyed by the map (H4bis).
- The nature of the map background influences the distribution of gaze (H5), as well as the transmission of the message conveyed (H5bis).

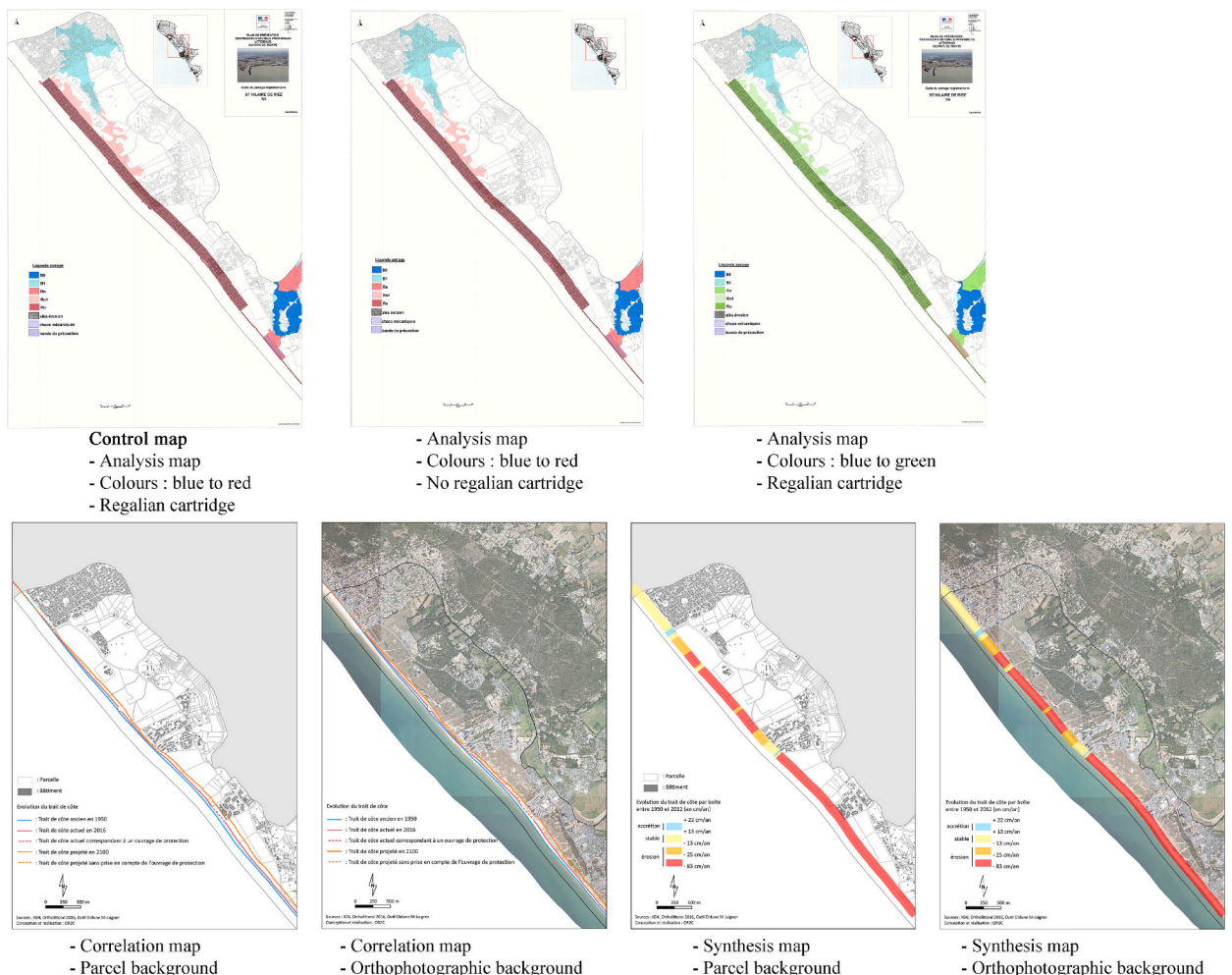


Fig. 1. Seven maps observed.

Given the influence of endogenous factors, we hypothesize that:

- The level of abstraction of the maps influences the distribution of gaze (H6), as well as the transmission of the message conveyed (H6bis).
- The regal cartridge (box on the map containing the official identification, authentication, and legitimation information for the map), inducing authority and trust, influences the distribution of gaze (H7), as well as the transmission of the message conveyed (H7bis).

3. Methodology

3.1. Participants

In order to meet these two objectives, a convenience sample of 50 citizens was selected for this experiment, including 31 women and 19 men, aged between 21 and 89 ($m = 50.1$, $SD = 18.2$). The participants lived in other communes than the one shown on the risk maps. Some of these communes are exposed to erosion risk, but none of the participants is personally exposed. 32 people knew the commune shown on the maps, and 30 had already been there (once in total to once a year). They were approached by posters in the various communes, by newsletters from certain town halls, or by direct contact with the public. All participants have normal or corrected eyesight. Participants were asked to wear contact lenses whenever possible, to avoid glare, and to refrain from wearing dark make-up around the eyes, so as not to interfere with the eye-tracker's pupil detection.

3.2. Material

3.2.1. Maps

Seven maps were tested in this experiment (Fig. 1):

- The official map (control map) currently used by the French government to communicate erosion risk to the population with red and blue colors and the State's regal cartouche. As an analysis map, it aims to structure information relating to the exposure of different areas of the municipality to coastal erosion by indicating their degree of exposure using colour blocks.
- A map without a regal cartridge.
- A map with modified colours (green instead of red).
- Two correlation maps (showing the evolution of the municipality's coastline at three different points in time: in 1950, in 2018, and a projection for 2100) but one with a parcel background and the other with an orthophotography background.
- Two synthesis maps (representing a detailed analysis of the evolution of the coastline by boxes between 1950 and 2012 in centimetres per year) with these two types of background maps as well.

The protocol being long and cumbersome, we anticipated the difficulties of recruiting participants and therefore the risk of a low amount of data by having each participant observe several maps and therefore testing the level of abstraction, the map colours and the presence of a regalian cartridge intra-individually. To increase the number of variables tested but limit the number of maps observed per participant, the background map was tested inter-individually. Each participant observed four maps representing coastal erosion in the same commune, but these four maps were not all the same from one participant to another, except for the control map. The latter is the official map, and the other three maps observed by the participant also depicted erosion in the same commune, but with varying characteristics, enabling to test different hypotheses thanks to several independent variables (IV):

- H7 and H7bis – regal cartridge effect (intra-individual IV): half the participants (group 1) saw a cartridge-less version of the control map.
- H4 and H4bis – colour effect (intra-individual IV): the other half of participants (group 2) saw a colour-modified version of the control map.
- H6 and H6bis – effect of abstraction level (intra-individual IV): all participants saw three different levels of map abstraction: an analysis map (control map), a correlation map, and a synthesis map.
- H5 and H5 bis – effect of map background (inter-individual IV): for half of the participants (group 1), the correlation and synthesis maps observed had a background based on a plot plan (not very detailed, representation of buildings and plots only), while the other half of participants (group 2) observed correlation and synthesis maps with a background based on an orthophotograph (very detailed, representation of buildings, natural areas etc.).

3.2.2. Psychometric scales and questionnaires

Two dependent variables (DVs) were measured before and after observation of the set of risk maps (H1, H2, H3) using psychometric scales: erosion risk perception and affect. Erosion risk perception was measured by the Coastal Flooding Risk Perception (CFRP) (Lemée et al., 2018), adapted here for erosion risk. It comprises 14 items assessing four dimensions: fear, collective vulnerability, risk increase, perceived risk knowledge. For each item, participants were asked to answer the extent to which they agreed with the statement on a five-point scale. Affective experience was measured by the Measure of Affectivity Valence/Activation (MAVA) (Congard et al., 2011) and considering two dimensions of affect: valence (pleasure/displeasure) and activation (arousal). The scale

comprises 16 items assessing four dimensions, each made up of four affects: Highly Activated Positive Affects, Lowly Activated Positive Affects, Highly Activated Negative Affects and Lowly Activated Negative Affects. For each item, the participant was asked to express the extent to which he/she felt each of the affects mentioned (one per item) on an 11-point scale. To lighten the experimental protocol (around 45 min per participant), a reduced version of these scales was proposed before the maps were observed (one item per dimension). The scores for each dimension of the two scales after observation were then divided by the number of items, so that pre- and post-observation scores were comparable. For each dimension of each scale, the item chosen is the one with the highest saturation in the associated factor of the factor analyses conducted in the studies validating the MAVA scale (Congard et al., 2011) and the CFRP scale (Lemée et al., 2018). However, regarding MAVA scale, another item was chosen for the Low-Level Activation Negative Affect that also had high saturation but was highly prototypical and more closely associated with the study objectives (“Anxiety” rather than “Gloominess”). Regarding CFRP scale, another item was chosen for the “Perceived knowledge” dimension. We preferred to select an item that did not have the highest load, but which seemed more prototypical of non-experts perceived knowledge: “To people like me, the risk of coastal erosion in the region is well known” rather than “I can estimate the chance of erosion risk”.

Eye-tracking data are purely objective but can be interpreted in different ways. It is impossible to know whether an object that has been stared at for a long time is more interesting than the rest of the scene, or more complex to analyse. To facilitate interpretation of the eye-tracking data, another DV was measured at the end of each map observation: the transmission quality of the message conveyed by the map. This variable was measured by means of seven questions evaluating the characteristics of the map (clarity, anxiety-inducing, reassuring...) on a scale of 0 to 10 (see Appendix B). The protocol was also completed by a semi-directive interview on map interpretation.

3.3. Procedure

The participant first read a study summary and signed a consent form concerning his/her participation in the study and the use of the data collected during the experiment. He/she then completed an online questionnaire (Appendix B) relating to socio-demographic characteristics, risk perception and affects scales. Then, definitions related to coastal erosion were shown on screen to ensure that all

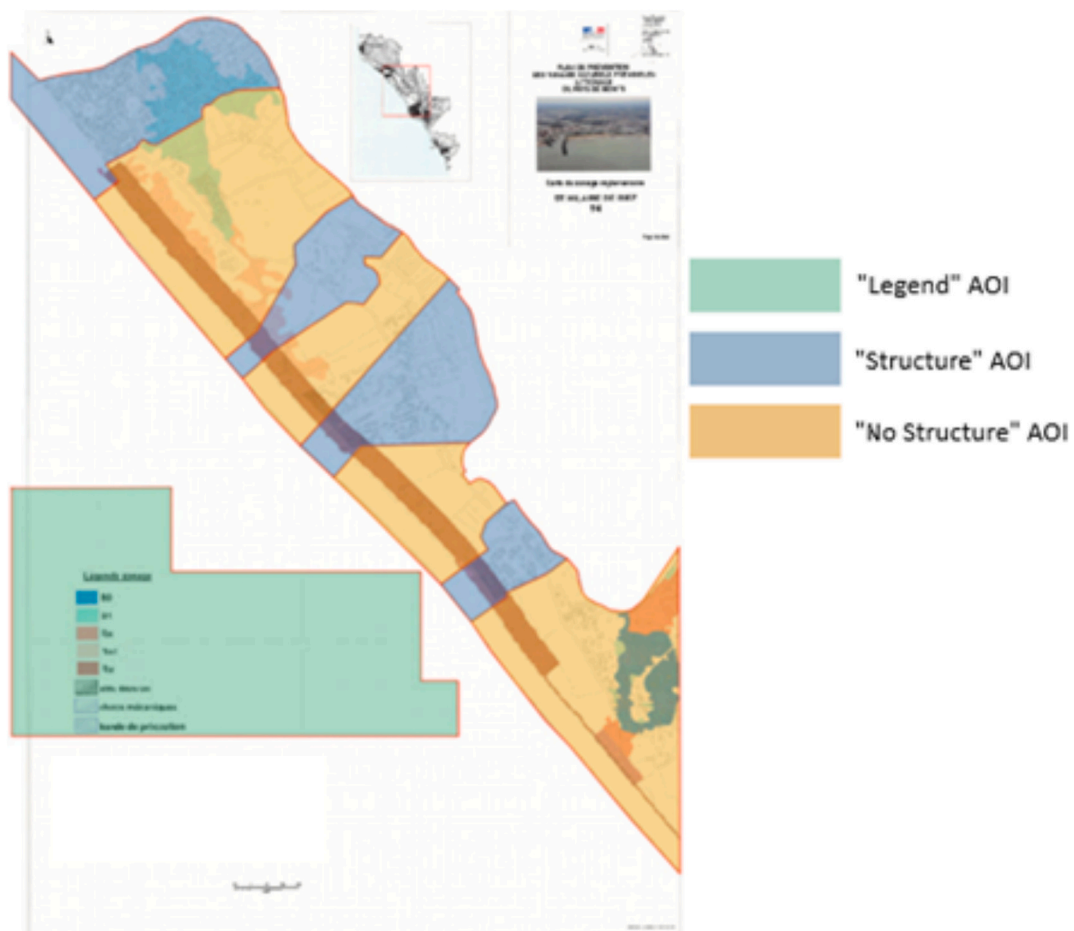


Fig. 2. Areas of Interest (AOIs) common to each map.

participants had the same minimum level of knowledge to understand all the maps. This also ensured that participants were able to read and see clearly what was displayed on the screen. Next, eye-tracking glasses were calibrated using the software's standard procedure, i.e. the appearance of five successive targets at different points on the screen. Participants were asked to find a comfortable position in which they could remain perfectly still. When the error rate was too high (>20 %), the procedure was repeated as many times as necessary until a satisfactory rate was achieved. Once the calibration was complete, participants observed four maps (one after another, each for two minutes). Following each observation, participants were asked to complete a brief online questionnaire in which they were asked to evaluate the map just presented. After all observations, they completed a final questionnaire (Appendix B), using the same scales as the first one but in their full version. The experiment ended with a semi-directive interview, recorded with the participant's consent, exploring maps qualities, semantics, visual salience and interpretation of the message conveyed.

3.4. Tools

Visual attention is measured using an eye-tracking tool. The Pupil Core eye-tracking glasses developed by Pupil Labs feature a camera that films the eye at a frequency of 120 Hz. Data relating to fixations are collected by Pupil Capture software and extracted by Pupil Player software. Visual attention can be operationalized in a number of ways using eye-tracking but is more conventionally operationalized on the basis of the number of fixations and the average fixation time. To analyse gaze distribution across maps, three areas of interest (AOIs) were defined, similar between the maps (Fig. 2): the "Legend" AOI (entire legend of each map), the "Structure" AOI (high-stake zones with protective structures against coastal erosion, since these zones usually include buildings and are exposed to coastal erosion), the "No Protective Structure" AOI (all the other zones shown on the map, where the stakes are lower). As AOI sizes are not the same, we used density of fixations (i.e. number fixations divided by the total surface area of the AOI) instead of number of fixations, to prevent the size of the AOIs from skewing the data. We also measured average fixation time, i.e. the average duration of all fixations placed on the AOI by each participant over the entire observation period. Fixation dispersion was set at 1.3° to account for participants' older age and frequent glasses use, which can cause gaze "tremors" (Blignaut, 2009), and thus "scatter" a single fixation over a slightly larger space. For maps combining observation and reading (where fixations are known to be very short, due to the gaze's scanning of words), a minimum threshold of identification is required.

3.5. Statistical analyses

To address hypotheses H1 for risk perception, and H2 and H3 for affect, a paired Student's t was applied to the total risk perception score, as well as to the scores for each dimension of both scales before and after observation of the four maps for each participant. Data were missing from three participants for the MAVA scale, and from a single participant for the CFRP scale. When the distribution of the data was not normal for certain dimensions of the two variables, a Wilcoxon test was applied to them.

Table 1 shows all the mean comparison tests carried out to validate hypotheses H4, H5, H6 and H7. For each, the two DVs (fixation density and mean fixation time) were compared between the AOIs of the different maps: each AOI is compared with that of the other map(s) operationalizing the IV, for both DVs. Some participants did not stand still despite the instruction, thus limiting the number of valid measurements for all the maps. Given the small number of data (less than 30) and the abnormality of the distribution of standardized residuals for some data, non-parametric tests were applied. With regard to hypothesis H5, as the sample was not balanced, it was not possible to compare the set of parcel-based maps with the set of orthophoto-based maps, while controlling for the level of abstraction of the map (correlation map or synthesis map). Two comparisons were therefore carried out in parallel: a comparison between map backgrounds for correlation maps and a comparison between map backgrounds for synthesis maps. Similarly, for hypothesis H6 on the level of abstraction, comparisons between maps with parcel backgrounds were made separately from comparisons between maps with orthophotography backgrounds.

Finally, for the hypotheses relating to the message transmission quality of the different maps (H4bis, H5bis, H6bis, H7bis), the scores for each question relating to message transmission quality were compared between the different maps relating to each hypothesis, either by a Wilcoxon test for intra-individual comparisons (H4bis, H6bis, H7bis), or by a Mann-Whitney test for inter-individual comparisons (H5bis). With regard to hypothesis H6bis concerning the level of abstraction, in order to avoid confounding variables, the two groups of inter-map comparisons were carried out separately: comparisons between maps with parcel background and the control map, and comparisons between maps with orthophotography background and the control map.

A post hoc power analysis was performed using G*Power software (version 3.1) to estimate the statistical power obtained from the sample size (N = 50) and the effect sizes observed in the various tests. For paired t-tests (minimum sample size: N = 50, minimum effect

Table 1
Statistical tests comparing the distribution of gaze on different maps.

Hypothesis	IV	Comparison	Measures	Statistical tests
H4	Map colours	3 AOI x 2 maps	Repeated	Wilcoxon test
H5	Background map (correlation map)	3 AOI x 2 maps	Independent	Mann-Whitney test
	Background map (synthesis map)	3 AOI x 2 maps	Independent	Mann-Whitney test
H6	level of abstraction (parcel base map)	3 AOI x 3 maps	Repeated	Friedman test (Conover post-hoc)
	level of abstraction (orthophotography base map)	3 AOI x 3 maps	Repeated	Friedman test (Conover post-hoc)
H7	Regalian cartridge	3 AOI x 2 maps	Repeated	Wilcoxon test

size of 0.5), the power achieved was 0.97. For Friedman tests (nonparametric ANOVA), the power of the tests was calculated based on that for a repeated measures ANOVA (1 factor, 3 levels, minimum sample size: N = 25, minimum effect size of 0.5), the power achieved was 1. For Wilcoxon paired tests (minimum sample size: N = 25, minimum effect size of 0.5), the power achieved was 0.77.

4. Results

4.1. Risk communication by maps, risk perception and affect

4.1.1. Risk perception

Hypothesis H1 that observation of coastal erosion risk maps increases risk perception cannot be validated, as there is no difference between scores before and after map observation. Nevertheless, the dimension of risk ignorance increases significantly after map observation (m = 1.78, SD = 0.73) compared to before (m = 1.43, SD = 1.22)(t(48) = -2.29, p < 0.05, d = -0.33). Conversely, the dimension of fear of risk was higher before map observation (m = 3.69, SD = 1.05) than after (m = 2.84, SD = 0.94)(t(48) = 6.27, p < 0.001), with a high effect size of 0.90.

4.1.2. Affective reactions

Hypotheses H2 and H3 concerning the increase in negative affects and the decrease in positive affect following observation of the risk maps are validated (Table 3). There was a significant decrease in High-Activation Positive Affects with a large effect size (t(46) = 7.62, p < 0.001, d = 1.111) after observation of the maps (m = 5.06, SD = 1.55) compared with the pre-observation phase (m = 6.68, SD = 1.58). Similarly, Low-Activation Positive Affects decreased significantly between the pre-observation measure (m = 7.21, SD = 1.73) and the post-observation measure (m = 6.46, SD = 1.82)(t(46) = 3.43, p < 0.001, d = 0.50). High-Activation Negative Affects increased significantly between the pre-observation phase (m = 2.43, SD = 2.46) and the post-observation phase (m = 3.00, SD = 2.22) (W = 229.5, p < 0.01, d = -0.492). However, there was no significant difference in Low-Activation Negative Affects.

4.1.3. Link between risk perception and affective reactions

Correlation tests (Pearson's r) between the dimensions of risk perception and the dimensions of the affect scale showed a significant positive correlation between low-level negative affect and ignorance of the risk (r = 0.31, p < 0.05) and a significant negative correlation between high-level negative affect and collective vulnerability (r = -0.29, p < 0.05). The other correlations were not significant.

Table 2

Comparison of fixation density and average fixation duration per AOI as a function of abstraction level.

Parcel-based map					
Density of fixations					
AOI by map	Control map	Correlation map	Synthesis map	$\chi^2F(2)$	Post-Hoc (Holm)
AOI « Legend »	104.40 (42.55)	136.71 (86.60)	154.33 (55.66)	10.30**	Control map < Synthesis map* (d = -0.78)
AOI « Structure »	91.90 (75.54)	261.18 (296.72)	305.40 (270.16)	5.20	Control map < Correlation map* (d = -0.72) Control map < Synthesis map* (d = -0.91)
AOI « No structure »	88.36 (62.71)	138.73 (101.11)	157.43 (133.04)	3.70	/
Average fixation time					
AOI « Legend »	555.46 (140.79)	322.83 (71.20)	458.49 (103.24)	32.44***	Control map > Correlation map*** (d = 2.14) Control map > Synthesis map*** (d = 0.89) Synthesis map > Correlation map*** (d = -1.25)
AOI « Structure »	775.73 (335.74)	1286.85 (564.41)	1270.56 (585.76)	8.44*	Control map < Correlation map** (d = -1.01) Control map < Synthesis map** (d = -0.97)
AOI « No structure »	999.98 (401.08)	1394.46 (504.80)	1352.35 (420.30)	8.11*	Control map < Correlation map* (d = -0.89) Control map < Synthesis map* (d = -0.79)
Orthophotography-based map					
Density of fixations					
AOI « Legend »	109.07 (68.18)	114.77 (84.06)	134.31 (104.27)	1.37	/
AOI « Structure »	90.79 (84.05)	162.50 (164.15)	220.40 (152.84)	12.19**	Control map < Synthesis map** (d = -0.94)
AOI « No structure »	99.16 (56.89)	111.37 (83.83)	142.61 (88.20)	2.11	/
Average fixation time					
AOI « Legend »	456.04 (198.15)	306.29 (92.47)	419.34 (103.70)	19.18***	Control map > Correlation map** (d = 1.07) Synthesis map > Correlation map*** (d = -0.81)
AOI « Structure »	748.12 (431.17)	1159.68 (616.15)	1072.41 (514.02)	8.15*	Correlation map > Control map* (d = -0.78)
AOI « No structure »	937.78 (411.45)	1350.90 (705.87)	1217.11 (515.15)	4.39	/

4.2. Influence of cartographic features on their observation and interpretation

4.2.1. Effect of map colours on observation

In order to answer hypothesis H4, the control map was compared to the map with modified colours. No difference in observation was observed for fixation density or average fixation duration, whatever the AOI.

Hypothesis H4bis concerning message transmission according to map colour was partially confirmed: the only significant difference out of the seven items evaluating this variable concerned the map with modified colours ($m = 2.33$, $SD = 2.37$), which was evaluated as significantly less easy to remember than the control map ($m = 3.17$, $SD = 2.79$), and this with a rather high effect size (Wilcoxon = 77.50, $p < 0.05$, effect size = 0.70).

4.2.2. Effect of map background on observation

In order to answer hypothesis H5, the correlation maps were compared with the orthophotography background, as were the synthesis maps. There was no difference between the correlation maps and the synthesis maps in the distribution of the gaze according to the map background, for both DVs.

Hypothesis H5bis concerning message transmission according to map background is not validated. No differences in the seven items were found between the two correlation maps. There was only one difference between the two synthesis maps: the one with orthophotography background was significantly more anxiety-provoking than the one with parcel background (Wilcoxon = 151.500, $p < 0.01$), with an effect size of -0.474.

4.2.3. Effect of abstraction level on map observation

In order to answer Hypothesis H6, three maps with different levels of abstraction were compared, but in two stages: on the one hand, maps with a parcel background, and on the other, maps with an orthophotography background. The results of the analyses are presented in Table 2.

In the case of the parcel-based maps, it can be seen that the fixation density is lower on the legend of the control map than on that of the synthesis map, but that these fixations are longer on average. We also note that the “Structure” AOI on the control map is less fixed (in terms of density or duration) than that on the correlation and synthesis maps. The “No structure” AOI is less fixed on the control map than on the other two maps. Finally, the legend on the correlation map is fixed for shorter periods than the legend on the other two maps.

In the case of the orthophotography background maps, the correlation map legend has shorter fixations than the other two maps. The “Structure” AOI on the synthesis map has a higher density of fixations than that on the control map, while the same AOI on the correlation map has longer fixations than on the control map. There is no difference between the “No structure” AOI.

Hypothesis H6bis relating to the transmission of the message according to the level of abstraction is partially validated. The three maps with orthophotography backgrounds varying according to the level of abstraction were compared on the one hand, and the three maps with parcel backgrounds were compared on the other (Table 3). The level of abstraction did not seem to influence the desire for further information, or the anxiety-provoking nature of the maps. But whatever the background map, the correlation and synthesis

Table 3
Comparison of message transmission quality as a function of abstraction level.

Items	Control map	Correlation map	Synthesis map	Friedman (2)	Post-hoc
Parcel-based map					
« This map expresses the risk very well »	4.58 (3.43)	8.54(1.56)	7.75 (1.94)	24.33***	Control map < Correlation map*** Control map < Synthesis map***
« This map is easy to read »	3.88 (3.15)	7.96(1.92)	7.29 (1.90)	23.87***	Control map < Correlation map*** Control map < Synthesis map***
« This map is difficult to understand »	6.25 (3.35)	2.33(2.37)	4.00 (3.18)	14.34***	Control map < Correlation map*** Control map < Synthesis map**
« This map makes you want to know more »	6.08 (3.43)	7.08(1.86)	7.25 (2.21)	2.00	/
« The message on this map is easy to remember »	3.17 (2.79)	7.96(1.78)	7.17 (2.46)	29.03***	Control map < Correlation map*** Control map < Synthesis map**
« This map is anxiety-provoking »	4.25 (2.79)	5.04(2.81)	5.79 (2.52)	5.31	/
« This map is reassuring »	2.88 (2.29)	3.21(2.43)	2.50 (1.79)	0.73	/
Orthophotography-based map					
« This map expresses the risk very well »	5.38 (3.10)	7.83(2.22)	7.17 (2.73)	9.69**	Control map < Correlation map**
« This map is easy to read »	3.79 (2.78)	8.21(1.93)	7.38 (2.16)	25.78***	Control map < Correlation map*** Control map < Synthesis map***
« This map is difficult to understand »	5.88 (3.03)	2.58(2.92)	3.33 (2.55)	9.30	Control map < Correlation map**
« This map makes you want to know more »	5.88 (3.03)	6.17(2.84)	6.88 (2.54)	4.11	/
« The message on this map is easy to remember »	2.96 (2.44)	7.29(2.27)	7.04 (2.27)	29.95***	Control map < Correlation map*** Control map < Synthesis map***
« This map is anxiety-provoking »	3.21 (2.78)	3.54(3.02)	3.41 (2.65)	1.97	/
« This map is reassuring »	2.00 (2.00)	3.25(3.08)	3.14 (2.21)	8.38*	Control map < Correlation ma* Control map < Synthesis map*

maps expressed the risk better, were more legible, less difficult to understand and easier to remember than the control map. Finally, we note that the control map is judged to be significantly less reassuring than the correlation and synthesis maps with orthophotography backgrounds.

4.2.4. Effect of the regalian cartridge on map observation

In order to answer hypothesis H7 concerning the impact of the presence of a regalian cartridge on map observation, the distribution of gaze on the control map was compared to that on the same map without a cartridge. There was no difference in observation either in terms of fixation density or average fixation time for the 'Legend' or 'structure' AOIs between the control map and the map without the cartridge. The duration of fixation is similar between the 'No structure' AOIs on the two maps, however, the density of fixations on the 'No structure' AOI on the map without the regalian cartridge is significantly higher than on the control map ($m = 84.15$, $SD = 64.10$) ($W = 58.00$, $p < 0.05$, effect size = -0.50).

Hypothesis H7bis relating to message transmission according to the presence of the regalian cartridge was not validated: no significant difference was found on the seven items relating to the quality of message transmission.

5. Discussion

5.1. Impact of communication with maps on risk perception and affects

A comparison of pre-observation and post-observation perceptions of erosion risk shows some unexpected results as providing information about erosion reduces risk perception but enhances negative affects. These results call into question the impact of map communication on its ultimate objective, i.e. to encourage risk-adapted decision-making and protective behaviour.

The reduction of risk perception can be explained by all participants interviews showing they had not understood the control map, and synthesis map raising certain questions about coastal dynamics. So, maps could be interpreted as too technical and aimed at experts, leading to difficulty in understanding, plus new questions and challenging certainties and beliefs. According to the literature on adaptation to risk, this increase in perceived ignorance may not be problematic since, on the one hand, the increase in knowledge correlates weakly with the adoption of adaptive behaviours (Salas Reyes et al., 2021) and, on the other hand, this feeling of lack of knowledge may lead people to seek information, a behaviour generally promoted in the context of risk management. Becoming aware of one's lack of knowledge can therefore be an objective sought through risk communication.

With regard to reducing the fear of risk, many participants noted the reassuring aspect of correlation maps because of their scale: the projections of successive coastlines over time are visually very close. The choice of map scale is therefore an essential variable to take into account if the message is to be conveyed effectively. Some studies have shown that a reduction in fear of risk explains a reduction in the behavioural intention to protect against natural hazards (Terpstra, 2011). But fear is not the only component of risk perception and does not always explain adaptive behaviour (Navarro, 2022). Moreover, it can even be counterproductive and hinder adaptation if it is not accompanied by a feeling of efficacy (Blondé and Girandola, 2016). The results of this study should therefore be further investigated by directly testing the impact of risk maps on decision-making (e.g. Kübler et al., 2019), taking into account the possible role of affects.

However, this result contradicts those of the affect scale, which show a significant increase in negative affect at high levels of activation. But it can be explained by the fact that the affect scale measures the current general affective state, whereas the fear measure in the perception scale is specifically related to the risk of erosion. The participants are not themselves exposed to this risk. The increase in negative affects and decrease in positive affects could therefore be due to other factors, such as fatigue at the end of the experiment. The apparently contradictory results between these two scales require further investigation, especially as the literature has shown the importance of the role played by affect in risk perception (Finucane and Holup, 2006), but also in the adoption of risk-related behaviours (Harries, 2012; Yang and Kahlor, 2013). Zaalberg et al. (2009) suggest that risk communication would benefit from being more emotionally vivid, which is difficult to determine in the context of this study. Some studies have shown that a reduction in fear of risk explains a reduction in the behavioural intention to protect against natural hazards (Terpstra, 2011). But fear is not the only component of risk perception and does not always explain adaptive behaviour (Navarro, 2022). Moreover, it can even be counterproductive and hinder adaptation if it is not accompanied by a feeling of efficacy (Blondé and Girandola, 2016). The results of this study should therefore be further investigated by directly testing the impact of risk maps on decision-making (e.g. Kübler et al., 2019), taking into account the possible role of affects, and by considering a population that is itself exposed.

The feeling of collective vulnerability is negatively correlated with negative affects at a high level of activation. Collective vulnerability refers to the fact that other people are also exposed to risk. As the participants were not themselves exposed to the risk of erosion, this result can be interpreted as a form of comparative optimism (Weinstein, 1980) whereby others are more exposed to risk than oneself, which has a reassuring effect and therefore reduces negative affect. On the other hand, the fact that perceived lack of knowledge of risk is positively correlated with negative affect at low levels of activation can be interpreted as a form of intolerance to uncertainty, the effects of which on negative affect have already been demonstrated in the literature (Ladouceur et al., 2000).

5.2. Influences of endogenous and exogenous characteristics of the map on observation

Level of abstraction seems to influence maps observation and interpretation: the correlation and synthesis maps are better at guiding attention towards the areas at stake, represented here by the 'structure' AOI, than the control map ('analysis map'), and these maps are evaluated as being more effective in conveying the message. The interviews corroborate these results since these first two

seem to enable the identification of protective structures and their effectiveness, as well as variations in the level of erosion and areas at risk. The distribution of gaze on these three maps and the interviews show that the legend is less accessible on the control map because of less dense but longer fixations. The opposite pattern on the synthesis map legend (more but shorter fixations) may indicate greater informativeness despite a certain complexity (*"The figures make you think 'less, more... How many? How much is 36?'" (P34)*). Research has shown the effect of a lack of familiarity with certain stimuli (endogenous factor) on the observation time needed to understand it, particularly in the context of reading. In addition, greater attention may be required when faced with a stimulus that is too difficult to read. Thus, whether we are talking about the legend of the control map or that of the synthesis map, the insistence on this area could be explained by its complexity or at least the lack of familiarity with it. The shorter duration of fixations on the correlation map legend can be explained by its sentence format, which induces a reading process in which the observer's fixations are shorter and follow each other in the order of the words. In terms of the quality of message transmission, the responses relating to the control map and the correlation map testify to the effectiveness of these two maps. And although there is no clear-cut result as to the influence of the level of abstraction on the reassuring or anxiety-provoking nature of the map, the interviews shed some light on their interpretation. The synthesis maps are both worrying (*"[...] 83 cm a year is worrying" (P11)*), and relief (*"It reassured me a little to see that it's not..." (P18)*), while the correlation maps seem rather reassuring because of the scale used and therefore the distance between successive coastlines, minimising the perceived risk (*"But the scale didn't do it any favours. Because the lines are relatively close together, it gives the impression that there's very little erosion" (P5)*). Conversely, evaluation questions and interviews indicate that the control map is less reassuring: *"Yeah, so this map might still be relatively anxiety-provoking." (P37)*. Finally, the results of the questionnaire do not show any effect of the level of abstraction on the intention to find out more. However, the participants did seem more curious or at least questioned viewing the synthesis maps: *"The rest is stable, and then all of a sudden it deteriorates. Why is that? Because of global warming? I don't know." (P10)*. This result is interesting in the context of risk communication since it also generally aims to encourage people to seek out information and then facilitate the adoption of adaptive behaviour (Terpstra et al., 2014). Another endogenous factor tested in this study was the presence of a regalian cartridge, but no effect was really evidenced either on gaze distribution or message interpretation. This cartridge could, however, constitute an argument of authority inciting action (e.g. protective behaviour) by legitimizing the information presented. It would therefore be interesting to study in more depth the influence of the regal cartridge by directly measuring behavioural intention or decision-making after consulting the maps.

In terms of bottom-up processes, no effect of the map background was observed on the distribution of gaze. However, Spachinger et al. (2008) showed that maps with more graphic information, for example with an orthophotography background, included significantly more fixations than maps with a black-and-white background, particularly among lay participants. In addition, Carter and Luke (2020) suggest that low-contrast maps make information less accessible because the gaze is spread more widely over the whole map. As the background of the map has no impact on the transmission of the message conveyed, the role of this variable should be explored further in future research. The other exogenous factor tested here was the colours of the map, but no effect was found on the distribution of the gaze or the interpretation of the message, apart from the fact that the map with the modified colours was less easy to remember than the control map. Nevertheless, the participants mentioned the importance of the semiology of colours during the interviews, in particular the fact that red is associated with danger and green with reassurance. Variations in colour would therefore allow a different interpretation of the message conveyed, based on the meaning attributed to the colours.

5.3. Limitations of the study

The first limitation of this study is the small sample size. In order to optimise the amount of data recorded for each participant and the number of variables tested in the study, the participants observed several maps, but not necessarily the same ones, which also halved the sample size for most of the analyses.

Secondly, risk perception and affect were only measured after all four maps had been observed, making it impossible to distinguish the specific effect of each map on these variables. In addition, as the experimental protocol was long and cumbersome, it was decided to reduce the questionnaire time in the first phase of the experiment, in order to conserve as much attentional resources as possible for observing the maps, on which the entire experiment was based. The risk perception and affect scales were therefore presented in a reduced version with a single item per dimension. But this method does not allow for the reliability of the measurement to be estimated, since only one item per dimension is used, and it reduces the sensitivity of the measurement. These reduced versions were created for the study and have not been psychometrically validated. Thus, although the results observed for these variables provide valuable insight into the effects of risk communication by map, they should be retested in future studies using complete or short scales that have been validated.

As mentioned earlier in the article, the eye-tracking data are objective data, the interpretation of which the questionnaires and interviews attempted to facilitate, but which remains at the discretion of the researchers. Furthermore, attention is not necessarily focused on the foveal vision (Duchowski, 2017) and a distinction has now been made between 'overt' and 'covert' attention. The former consists of the concentration of attention towards where foveal vision is centred, while the latter concerns situations in which attention is directed either towards the periphery of the gaze or towards other sensory stimuli (Borji and Itti, 2013). Measuring ocular activity is therefore no guarantee of specifically measuring attention.

Finally, the maps chosen for the experiment all represent the same commune, which the participants were selected not to live in. The aim was to avoid observation bias related to familiarity with the map of the commune, or to the fact that visual attention might be focused on places known to the participant (their own place of residence, places usually frequented, etc.), as these factors are difficult to identify precisely and therefore to control. However, in a real-life situation, residents would tend to look at maps relating to their own commune, with which they might be more familiar, which could therefore lead to different processes. In addition, these residents

were not themselves exposed to the risk of erosion, which could have an impact on the reading and interpretation of the maps, as well as on their influence on the perception of risk and affect. We can also add that risk maps are often consulted in emergency situations, which can be stressful and may influence how the information is read and processed. However, the observation time for this study was relatively long for each map and without any particular stakes. We therefore propose to further this work by studying the observation of risk maps by residents exposed to the risk represented, and who live in the municipality represented. We also suggest repeating this type of protocol by inducing a form of stress, for example by drastically limiting the observation time for each map, or by causing emotional stress just before the Observation (e.g., an evaluation or public speaking).

6. Conclusion

The mixed results concerning the influence of map communication on risk perception demonstrate the need to continue work on this type of medium, but also the importance of thinking about risk communication beyond the simple transmission of information, since other processes are obviously involved. The use of this type of medium is therefore not trivial and can even be counter-productive depending on the aim if all the parameters are not taken into account. Furthermore, [Luís et al. \(2016\)](#) have shown that a high level of risk awareness, fuelled in particular by information, is not necessarily accompanied by a high level of risk perception. Risk communication must therefore do more than simply transmit information. In particular, it can appeal to emotions, which in turn can have an impact on risk perception and behaviour ([Salas Reyes et al., 2021](#)). But the perception of risk and fear alone do not determine the adoption of adaptive behaviours, as fear can limit them if it is not accompanied by a feeling of efficacy in the face of risk ([Blondé and Girandola, 2016](#); [Navarro, 2022](#)). The results of this study do not, therefore, map the risk of unsuitable media for communication, but show that this field of research would benefit from further exploration of the processes at work when faced with this type of medium, as well as its impact on the adoption of adaptive behaviours.

This study also helps to guide the choice of communication media in the context of map-based communication, as the different maps are not observed and interpreted in the same way. All of the data collected concerning the control map, proposed by the government services to citizens exposed to coastal risks, show that it is not sufficiently clear, and that attention is not directed towards the key areas, which should be at the heart of the message conveyed by the map. Conversely, the synthesis and correlation maps are more accessible and better at directing attention to the relevant areas, although the synthesis map appears to be a little more complex for non-experts.

In conclusion, we suggest the use of correlation maps representing the evolution of the coastline over time to represent the risk of coastal erosion when communicating to the non-expert public. Moreover, this map includes elements already recommended in the study by [Meyer et al. \(2012\)](#) for better understanding by the general public: representations of defences, use of text, non-expert vocabulary. However, the scale needs to be carefully considered to avoid minimising the risk. The colours do not influence the observation pattern or the interpretation of the message, but we do recommend using colours derived from the socio-cultural context in order to make the message easier to understand (in this case, red for danger, for example). In this study, map background does not influence map observation or interpretation. However, based on previous work, we still suggest using a simplified parcel-type background showing buildings and roads to facilitate identification and understanding ([Spachinger et al., 2008](#); [Meyer et al., 2012](#)). These recommendations provide a basis for developing maps that are understood by the general public, but do not necessarily promote the standardisation of risk maps. [Meyer et al. \(2012\)](#) have already shown the strong interest of plural maps adapted to the regional needs and preferences of the various stakeholders. They also showed that specification of these maps can be promoted through participatory processes that enable stakeholders to identify the limitations of current representations and contribute to their improvement, notably by integrating forms of local knowledge.

CRedit authorship contribution statement

Naud Aude: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Navarro Oscar:** Supervision, Methodology, Conceptualization, Writing – review & editing. **Chotard Manon:** Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Juigner Martin:** Visualization, Resources, Methodology, Conceptualization. **Robin Marc:** Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Chadenas Céline:** Supervision, Methodology, Conceptualization. **Fleury-Bahi Ghazlane:** Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.crm.2025.100738>.

Data availability

I have shared the link to my data at the end of the manuscript

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