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Drivers and dimensions of flood risk perceptions: Revealing an implicit selection bias and lessons for communication policies

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ABSTRACT

Flood damages have increased in many regions around the world, and they are expected to continue to rise in the future due to climate change. To reverse this trend, awareness of flood risk among the population is required to support flood risk management policies and improve flood preparedness. However, empirical studies on the drivers of flood risk perceptions conducted thus far have reported mixed and contradictory results. The aim of this study is to provide insights into the factors that influence perceptions of various dimensions of flood risk to draw lessons to guide flood risk communication strategies. We test a variety of hypotheses of possible factors of influence on flood risk perceptions that are motivated by theoretical concepts and previous empirical studies, whilst also controlling for socio-demographic variables. A representative sample of 2,976 residents answered our survey assessing the role that past flood experiences and risk communication play in shaping flood risk perceptions. Besides exploring flood risk perceptions more robustly, this large sample also facilitates the systematic study of 'don't know' answers, which are often dismissed as missing data in many studies. Rather in this study we analyze what 'don't know' answers reflect in terms of knowledge about particular dimensions of flood risk. The study finds that older people, as well as those who have higher levels of income and education, are significantly more likely to express their flood risk perceptions, respondents who are unable to answer the questions on flood risk perceptions face a lower flood risk, report to have been living in their neighbourhood for a shorter period of time and have less first-hand flood experience. Previous studies might thus be biased by an implicit selection effect. Finally, we show that findings are highly dependent on other explicit choices made by researchers, including the apparently self-fulfilling impact of selecting one explanatory framework over another. New insights emerge from the role that information campaigns and social vulnerability play in the ability to answer the questions. Based on our findings, we offer recommendations for improving flood risk communication policies, specifically increasing the frequency of communication, ensuring that campaigns are focused in terms of the content they provide and the subgroups of the population they target.

1. Introduction

Natural disaster losses, particularly flood damages, have been increasing in many regions around the world in the past decades. The causes are mainly attributed to population and economic growth in disaster-prone areas (Coronese et al. 2019). In the future, these socio-economic trends are expected to continue, and flood risk is also projected to rise in some areas due to climate change (IPCC 2014). To limit the trends in flood risk, additional integrated flood risk management strategies are required. In addition to the deployment of flood protection infrastructure, other strategies include measures for limiting potential flood damage and emergency preparedness plans, such as evacuation to curb health risks during floods (Reghezza and Rufat, 2015). A higher degree of awareness about flood risks or risk perceptions among the population is also necessary to facilitate the implementation of such measures. The reason is that risk perceptions are important drivers of support for public sector flood risk management policies and flood preparedness decisions, including the flood-proofing of buildings and

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evacuation (Bradford et al. 2012; Buchecker et al., 2016).

Flood risks can be characterised as low-probability/high-consequence risks that are often underestimated by individuals unless these individuals experience a flood event after which risk perceptions temporarily rise (Botzen et al. 2015). People underestimating flood risks is a major problem in risk management. Although flood damage mitigation measures are effective (Poussin et al. 2015), many households in flood-prone areas do not adopt these measures, which is partially attributed to low flood risk perceptions (Poussin et al. 2014). Knowledge about the factors influencing flood risk perceptions can contribute to solutions for this problem, for instance, by allowing the development of targeted communication strategies that raise awareness of flood risk and improve preparedness (Becker et al., 2014; Rufat et al. 2020). Our study aims to improve insights into the influential factors and perceptions of various dimensions of flood risks to draw lessons that help in guiding flood risk communication strategies.

Here we refer to the emergent literature on flood risk perceptions. Eight review studies on flood risk perception have been published during the past two decades (Boholm 1998; Bradford et al. 2012; Bubeck et al. 2012; Wachinger et al. 2013; Kellens et al. 2013; Birkholz et al. 2014; Raška, 2015; Lechowska 2018). They have consistently found that empirical studies on flood risk perception conducted thus far are reporting contradictory results. This mixed evidence hampers the provision of clear recommendations for flood risk management, such as the design of targeted risk communication strategies (Höppner et al. 2012; Wachinger et al. 2013). This mixed evidence often remains unchallenged because of heterogeneous approaches and methods – and many studies refrain from using theories for deductive analysis – thereby hindering the comparison of results from different studies (Kellens et al. 2013). Moreover, competing theories about risk perception and behaviour are used in several studies that test for a limited sets of hypotheses, drivers, or control variables. This approach results in findings that are not easily rendered compatible (Lechowska 2018). Finally, many previous studies merely focused on a limited set of dimensions of flood risk perceptions, such as awareness and worry (Lechowska, 2018); a more comprehensive assessment of various dimensions can contribute to a more in-depth understanding of risk perception.

In our study, we overcome some of the limitations of previous research on flood risk perceptions by testing a variety of hypotheses of influential factors on the various dimensions of flood risk perceptions that are motivated by theoretical concepts and previous empirical studies, while also controlling for socio-demographics in our regression analysis. In particular, we seek a more comprehensive understanding by assessing eight different dimensions of flood risk perceptions, including awareness, perceived likelihood and consequences, relative exposure, and feelings toward flood risk, such as worry and trust. Our regression methods move beyond simple correlation analyses by estimating the independent effects of a range of drivers on flood risk perceptions and exploring the impacts of sampling effects, variable selection, and more fundamentally, the choice of one set of explanations over another. Through a survey, we collected data on flood risk perceptions in the fall of 2018 from households in Paris, France. Two flood events in 2016 and 2018 and one major European flood simulation in 2016 occurred prior to our study, each of which was salient enough to receive extensive international coverage. Shortly before the floods, a 2015 study by the Organisation for Economic Co-operation and Development (OECD) included a warning about fading flood memory and recommended the intensification of risk awareness (Baubion 2015). The study indicated that a major flooding of the Seine River could affect approximately five million residents and cause damage worth €30 billion. This specific setting enables the drawing of lessons for communication policies by assessing the effects on flood risk perceptions by actual disasters and risk communication strategies. The latter is scarcely investigated as highlighted in the review by Kellens et al. (2013).

A representative sample of 2,976 residents answered the survey. An advantage of our sample is that it is considerably larger than the ones in most previous studies. Such sample size also facilitates the assessment of the factors of influence on survey "don't know" answers, which are often overlooked in the existing literature that treats them as missing observations. Instead, we analysed these responses and found that they provide relevant insights into the reasons why a subgroup of the sample is unable to give an estimate to specific flood risk perception questions. Our results reveal that an implicit selection bias existed in previous studies, which might have resulted in the elimination of such responses.

2. Theoretical framework

Daniel Kahneman (2011a) summarises decades of behavioural decision research and identifies two thinking modes that drive individual behaviour, namely System 1 and System 2 (sometimes also respectively referred to as the experiential and analytical systems, as in Slovic et al. 2004). This umbrella framework characterises thought processes that originate from the classical economic theory of rational behaviour and insights from behavioural economics and psychology, as follows:

- System 1 automatically and rapidly operates with little or no effort and no sense of voluntary control.
- System 2 allocates attention to the effortful mental activities that demand it, including simple or complex calculations or formal logic.

System 1 includes emotional reactions and feelings toward risks, such as worry (Loewenstein et al. 2001). It has been associated with biases and systematic errors, especially if decisions about unfamiliar topics are to be made, such as assessing low-probability/high-impact risks, including flood risk (Kunreuther et al. 2012). For example, System 1 processes may be heavily influenced by personal experiences with a hazard. The relevance of such an 'availability heuristic' in risk perception was discussed by Tversky and Kahneman (1973). Heuristics are simple rules at work in the human brain, which help people to promptly process the complex reality (Tversky and Kahneman 1974). For example, individuals who have recently experienced a flood may find the scenario of a future flood easier to imagine; therefore, they express a higher perceived risk than people without flood experience (Botzen et al. 2009; Kunreuther and Michel-Kerjan 2015). The 'affect heuristic' acknowledges the importance of affective feelings in shaping risk judgments (Slovic et al. 2004). When floods are associated with negative feelings or memories, respondents may declare a higher risk perception (Finucane et al., 2000a; Finucane et al., 2000b). In that case, 'heuristics' can be interacting, as previous experiences with flooding or evacuation (availability heuristic) might produce or reinforce negative feelings (affect heuristic).

By contrast, System 2 considers the risk that entails a more systematic and effortful evaluation of the available information. Furthermore, this system may be categorised as the standard rational economic model of behaviour, such as subjective expected utility theory (SEUT); SEUT assumes that people assess the likelihood and consequences of alternative choices (Savage 1954). For example, individuals would assess the likelihood and consequences of a flood and subsequently decide whether undertaking any action to reduce their flood risk is worthwhile. Kunreuther and Pauly (2004) augment the SEUT model by postulating that consumers incur implicit or explicit transaction costs associated with obtaining information about underlying loss probabilities. They indicate that if the costs of acquiring risk information are high and/or the perceived loss probability is low, then individuals may not be fully informed about risk, and thus, may be discouraged from insuring against disasters. According to the notion of 'bounded rationality', individuals are unlikely to be fully informed about flood risk (Conlisk 1996). However, risk perceptions can still be expected to be positively related to the actual levels of risk (Kahneman 2011b). The reason is that people who face a relatively high flood risk have higher benefits from being informed than individuals who face a relatively low flood risk. The reason is that people at high risk have more to lose from a flood disaster if information or preparation is inadequate. Moreover, the mental cost of searching for information may be reduced through campaigns; in other words, risk perceptions may be influenced by effective risk communication and brought in line with actual risk if individuals apply System 2 thinking and undertake efforts to evaluate information from risk communication campaigns.

In summary, both System 1 and System 2 thinking processes are likely to shape individual perceptions of risk and decision making with regard to risk. Hence, in Section 3, we derive hypotheses that are grounded in both of these systems.

3. Risk perception variables and hypotheses

The choice of our risk perception variables was guided by the psychometric approach involving a quantitative analysis of expressed preferences and attitudes (Fischhoff et al. 1978). Respondents were asked to express their perceptions on rating scales about awareness, various characteristics of the risk (severity, probability), abilities to cope (knowledge, controllability), feelings (worry), and attitudes toward risk management (trust). Psychometric research confirms that the more a person worries about a hazard or regards it as uncontrollable, unpredictable, unknown, catastrophic, or unequal, the higher is the perceived risk (Slovic 1987). However, most empirical studies focus on flood risk awareness or worry, whereas a few extend to a combination of worry, awareness, severity probability, and/or preparedness (Wachinger et al. 2013; Lechowska 2018). In contrast, our study design includes more dimensions of risk perception, which include the initial dimensions from the psychometric approach (worry, probability, trust, prediction, control, consequences) plus space (perceived exposure) and time (duration) dimensions (Lindell and Hwang 2008).

The choice of our explanatory variables is guided by the umbrella framework of System 1 and System 2 thinking about risk. As explained in the next subsections, we examine the influence of the availability heuristic that is a part of System 1 thinking using the explanatory variables of flood experience (Section 3.1). The influence on risk perceptions of actual risk, awareness of information on living in a flood risk zone, and other risk communications are analysed as a part of System 2 thinking processes (Section 3.2). Moreover, several socio-demographic characteristics are included as control variables in our models of influential factors on flood risk perceptions (Section 3.3). This inclusion is important because the mixed results on the drivers of risk perceptions that have been reported thus far (Bubeck et al. 2012; Lechowska 2018) failed to account for the interacting effects of such factors on risk perceptions. Only a few previous studies included these explanatory variables or controlled them in regression analysis, rather they estimated simple correlations (Brilly and Polic 2005; Rufat 2015; Lechowska 2018).

3.1. Availability heuristic (System 1)

Consistent with the availability heuristic (System 1), previous experience with floods is frequently found to positively impact flood risk perceptions (Keller et al. 2006; Siegrist and Gutscher 2006; Botzen et al. 2009; Reynaud et al. 2013; Botzen et al. 2015; Richert et al. 2017; Royal and Walls 2019). Therefore, we expect flood experiences and the resulting power, water or heating outages, and sewer backflow that might last for several days after a flood to have positive relationships with flood risk perceptions, especially because of the recent floods in Paris (2016 and 2018).

Hypothesis 1a. *Respondents with flood experience have higher perceptions of flood risk.*

Hypothesis 1b. *Respondents with severe outage experiences after a flood event have a higher awareness of the flood's indirect effects.*

3.2. Actual risk and risk communication (System 2)

Consistent with the rational model (System 2), we expect a positive relationship between risk perception and actual flood risk. Although this finding is not universally observed (Pagneux et al. 2011), many previous studies have established such a positive relationship (Brilly and Polic 2005; Siegrist and Gutscher 2006; Miceli et al. 2008; Lindell and Hwang 2008; Raaijmakers et al. 2008; Botzen et al. 2009; Zhang et al. 2010; Botzen et al. 2015; Rufat 2015; O'Neill et al. 2016). Moreover, we expect a negative relationship between the floor of residence and risk perception. People living in single-family homes or apartments on the lower floors may realise that they are more exposed to the direct effects of floods than those living in apartments on the upper floors.

Hypothesis 2a. *Respondents who live in an area with a higher flood risk have higher flood risk perceptions than those who live in an area with a lower flood risk.*

Hypothesis 2b. *Respondents who live on higher floors have lower flood risk perceptions than those who live on lower floors (or single-family homes).*

Risk perceptions based on actual flood risk assume a high degree of individual rationality. Although this still falls in the realm of rational decision models, this assumption has been relaxed in the SEUT model. Here, individual decisions under risk can be based on the imperfect knowledge of actual risks, such as awareness of living in a flood zone. We expect this awareness to have a stronger impact on risk perception than the actual location of the residence inside or outside of the flood delineation zone (Bradford et al. 2012). The reason is that some people may be unaware of whether they live in a flood zone, while their (perhaps incorrect) knowledge of it can influence other flood risk perceptions. To a lesser extent, we expect similar impacts for awareness of living in a zone where floods have indirect effects (e.g., power, water, and/or sewage outages).

Hypothesis 3a. *Respondents who are aware that they live in a flood-prone area have higher flood risk perceptions than those who are unaware of this situation.*

Hypothesis 3b. *Respondents who are aware that they live in an indirect effect zone have higher flood risk perceptions than those who are unaware of this situation.*

Risk communication strategies that are often implemented by governments can raise risk awareness and bring risk perceptions more in line with the actual risk that the residents confront. This is important because new residents in flood-prone areas may be unaware of flood risk; meanwhile, the risk perceptions of existing residents who have experienced floods may decline over time when memories of flood events disappear (Bin and Landry 2013). Very few studies have directly examined the influence of risk communication on flood risk perceptions (Kellens et al. 2013). Those studies revealed weak effects (Terpstra et al. 2009), highlighting the challenges of designing effective communication campaigns. Nevertheless, we expect official information on floods to have a positive relationship with risk perception. We also hypothesise that the memory of previous exercises in which a flood was simulated in Paris and broadcasted over media is positively related to risk perceptions. Furthermore, we expect a positive relationship between flood risk perceptions and the respondent's self-reported preparedness because this preparedness was stressed during risk communication campaigns.

Hypothesis 4a. *Respondents with knowledge of official flood risk communication have higher perceptions of flood risk.*

Hypothesis 4b. *Respondents with the memory of previous flood exercises have higher perceptions of flood risk.*

Hypothesis 4c. *Respondents with higher self-reported flood preparedness have higher perceptions of flood risk.*

3.3. Socio-demographic characteristics

Socio-demographic characteristics are the most contested drivers of risk perception. For example, although the 'white male effect' is well documented, with white males expressing lower risk perceptions than women and minorities (Olofsson and Rashid, 2011), other studies found no relationship with gender (Lechowska 2018). Some studies similarly observed that less educated people worry more about flooding (Bradford et al. 2012), whereas others found no such effect (Kuhlicke et al. 2011). Several studies attributed such an effect to the relationship between education and income (Wachinger et al. 2013). Furthermore, some studies concluded that immigrants and socially vulnerable communities have lower levels of self-protection and flood knowledge, and consequently, higher risk perceptions (Maldonado et al. 2016). Other studies attributed such effects to characteristics such as age and income (Adelekan and Asiyanbi, 2016), or residential segregation (Rufat 2015). Some studies also revealed that older and higher income residents have higher risk perceptions and more often adopt precautionary measures (Grothmann and Reusswig, 2006), whereas other studies found that age (Armas et al. 2015; Botzen and Van Den Bergh, 2012) or income (Lindell and Hwan, 2008; Botzen et al. 2009) had no significant impacts. Moreover, the length of residence in the same place may be negatively related to flood risk perceptions, especially when controlling the previous flood experience (Lazo, 2009). False alarms might produce a false sense of security (Peacock et al. 2005), and people who live in the area for a long time may have experienced more false alarms (Baker 1991).

To allow for a more robust testing of our hypothesis and explore the effects of variable selection, we also used these socio-demographic characteristics as explanatory variables in our study, given that the literature has considered them as important influencers for flood risk perceptions.

Control variables 1 *Male respondents have lower flood risk perceptions than female and minority respondents ('white male effect').*

Control variables 2 *Older respondents have higher flood risk perceptions than younger respondents.*

Control variables 3 *Respondents in socially vulnerable situations (defined as having less education, low income, young children, and/or a disability, and being non-native French speakers, renters, minorities, and/or single-headed households) have higher flood risk perceptions than other respondents.*

Control variables 4 *Respondents with more living experience in a flood-prone area have lower perceptions of flood risk.*

We expect that socio-demographic characteristics can have contrasting connections to the various risk perception dimensions (i.e. age having a positive relationship with worry but a negative relationship with the perceived flood probability and consequences). Moreover, we expect that the conflicting effects of socio-demographics found in the literature are caused by the choice of statistical methods and the selection of explanatory variables.

4. Methods

4.1. Survey and variables

The survey was administered face-to-face in the Paris metropolitan area from September to December 2018, to a representative sample (n = 2,976) of the population; random sampling and spatial and social stratification were employed to ensure the representativeness at different scales. Half of the sample consisted of residents living in the flood zone, and one-third of the sample included respondents living in the indirect impact zones, indicating that while their homes might not be flooded, they might still face power, water or heating outages, sewer backflow, and similar situations that might last for several days. The rest of the sampled respondents lived outside the direct and indirect exposure zones, and they were considered the control group. The questionnaire was administered face-to-face with geolocation of the place of residence, which is used to compute actual flood risk, with a 100 m buffer to ensure privacy. The full questionnaire comprised 80 questions and required 15–20 min to complete.

Supplementary Tables 1 and 2 provide an overview of the dependent variables and their specific definitions and coding. The dependent variables represent the eight dimensions of flood risk perception, namely worry for floods, trust in flood forecasts, controllability of floods, their frequency, consequences, predictability, duration, and the perceived relative exposure to floods (compared with other people in Paris). These variables are coded such that an increasing scale always denotes higher risk perceptions. For each of the questions in the questionnaire, a 'don't know' option was offered to avoid forcing respondents to select a biased answer when they were unaware. We derived variables representing such lack of answers to specific questions when more than 300 respondents were unable to give an estimate. This case was true for six variables (i.e., controllability, frequency, consequences, prediction, duration, and exposure). As virtually all the respondents answered the question on worry but only half answered the question on flood duration, we interpret them as respondents who do not know how to answer rather than issues of mistrust or disregard. We derived worry for floods relative to worry for terrorist attacks; terrorism is a salient risk because of the attacks that occurred in Paris in 2015. Finally, three variables compared the official flood risk and perceived exposure: being right about living in the flood zone or in the direct or indirect effect zone and being rightly safe (outside of the direct and indirect impacts zones). Supplementary Table 3 provides an overview of the explanatory variables and their specific definitions and coding. We selected the explanatory variables to represent two main groups derived from our hypotheses and previous empirical studies: one group of variables related to previous experience, actual risk, awareness, and information campaigns, and another group of residential and socio-demographic characteristics.

4.2. Statistical methods

Most of the previous empirical studies apply simple correlation analyses, chi-squared tests, or t-tests to estimate the effects of a wide range of explanatory variables on risk perception. However, regression analyses are required to disentangle the independent effects of the various explanatory variables. Hence, we estimated ordered logit models for ordered categorical dependent variables and binomial regression models for binary dependent variables. We also performed correlation analyses to compare the results between different methods and to check that the variable selection did not induce multicollinearity issues.

Each time, we used one model for each of the 18 dependent variables to explore the possible contrasting impacts of the explanatory variables on the different dimensions of flood risk perception. Following other studies (Bubeck et al. 2013; Poussin et al. 2014), we estimated the regressions using a stepwise approach: starting for each model with all the selected explanatory variables and incrementally discarding the least significant one, until the model fitted only on significant variables. These final regression results are reported in the next section, and the initial full model results are in Supplementary Table 4. Finally, we investigated whether the various risk perception drivers return the same results when used separately or in combination, by sequentially running several analyses. An analysis reported in Supplementary Tables 5 and 6 includes only the official flood risk, experience, and information explanatory variables. Another analysis in Supplementary Tables 7 and 8 merely involves socio-demographics and residential characteristics. All the explanatory variables were simultaneously included in the main models used to test the hypotheses.

5. Results

5.1. Exploring the dimensions of flood risk perception

Each dimension of flood risk perceptions was elicited by a separate survey question. Fig. 1 reports these answers, including the number of respondents who failed to give an estimate. The distribution of responses between the different answer options is fairly balanced each time, except ‘In my neighbourhood, floods are very frequent’ (top of the rating scale), which obtained<1% of the responses, and ‘In my neighbourhood, floods can last 4 to 5 weeks (also the top of the scale), which garnered only 3% of the responses. The presence of an interesting heterogeneity in flood risk perceptions to be explored in regression analyses is illustrated in Fig. 1.

Many people have inaccurate perceptions of the flood risks that they face. Although half of the sampled respondents are living in the official flood delineation zone, only one respondent in five is aware that they can be directly affected by floods. Only one-third of the respondents exposed to floods rightly perceived themselves as living in the flood zone, whereas two-thirds perceived themselves as living outside of the flood zone. Only 10% wrongly assumed that they lived in the flood zone, while living out of it (Table 1). All these differences are statistically significant. Similarly, four out of 10 affected parties rightly perceived themselves as living in the indirect effect zone, whereas more than half wrongly perceived themselves to be safe while living either in the indirect effect or flood zone.

These results were used to compute three new variables: ‘rightly exposed (flood zone only)’, ‘rightly exposed (flood zone and indirect effects)’, and ‘rightly safe’ (Supplementary Table 2). A comparison of the answers about worry for floods and terrorist attacks revealed that a larger group (38%) worry more about terrorism than floods compared with people worrying more about floods (15%), which we used for computing a new variable: ‘worry more about floods or terrorist attacks’ (Supplementary Table 2).

5.2. Correlations and heat map

Fig. 2 illustrates a Pearson correlation matrix of all the dependent and explanatory variables, with statistically significant correlations ($p < 0.01$) highlighted in red for positive and in blue for negative correlations. The flood risk perception variables are positively and significantly related to each other, but they are negatively and significantly related to being rightly safe, as would be expected. Almost none of the sociodemographic characteristics have a significant relationship with risk perceptions, except for age (positive correlation) and floor of the residence (negative correlation). All the variables reflecting actual flood risk, previous flood experience, information, and preparedness are systematically, positively related to flood risk perceptions (negatively in the case of being rightly safe), including a lesser extent knowledge of official risk information. Correlations over 0.5 among the explanatory variables are non-existent, which implies that the variable selection does not induce multicollinearity issues. All the explanatory variables are consequently retained for the regressions to disentangle the independent effects of each factor, except for disability and self-reported minority, for which we find no significant relationship with any of the flood perception dimensions or ‘don’t know’ answers when controlling for other drivers.

Table 1
Comparison of actual and perceived exposure to floods.

	Is your home in a flood risk zone?			
Actual exposure	No	Yes	Don’t know	Sum
None	447 *(77%)*	33 *(6%)*	103 *(18%)*	583 *(100%)*
Indirect effect	560 *(64%)*	114 *(13%)*	199 *(23%)*	873 *(100%)*
Flood zone	723 *(48%)*	488 *(32%)*	309 *(20%)*	1520 *(100%)*
Sum	1730 *(58%)*	635 *(21%)*	611 *(21%)*	2976 *(100%)*

chi-squared = 251.43, df = 4, p-value < 0.00001

5.3. Models of flood risk perceptions with all the explanatory variables

Table 2 presents the results of 18 models of perceptions of various dimensions of flood risk and the inability of respondents to answer risk perception questions using all the explanatory variables, based on a stepwise regression approach. The pseudo-R^2 values between 0.19 and 0.50 indicate that all the models provide a good fit for the data. In most cases, predictors have an impact in the expected direction that is consistent across models. The results are largely confirmed by the full models (Supplementary Table 4).

5.3.1. Results in relation to our core hypotheses

The results of the models of the various flood risk dimensions in the first eight columns of Table 2 constitute the basis for our hypotheses. A general pattern is that the most significant effects are observed for the variables that represent flood experience, actual flood risk, and

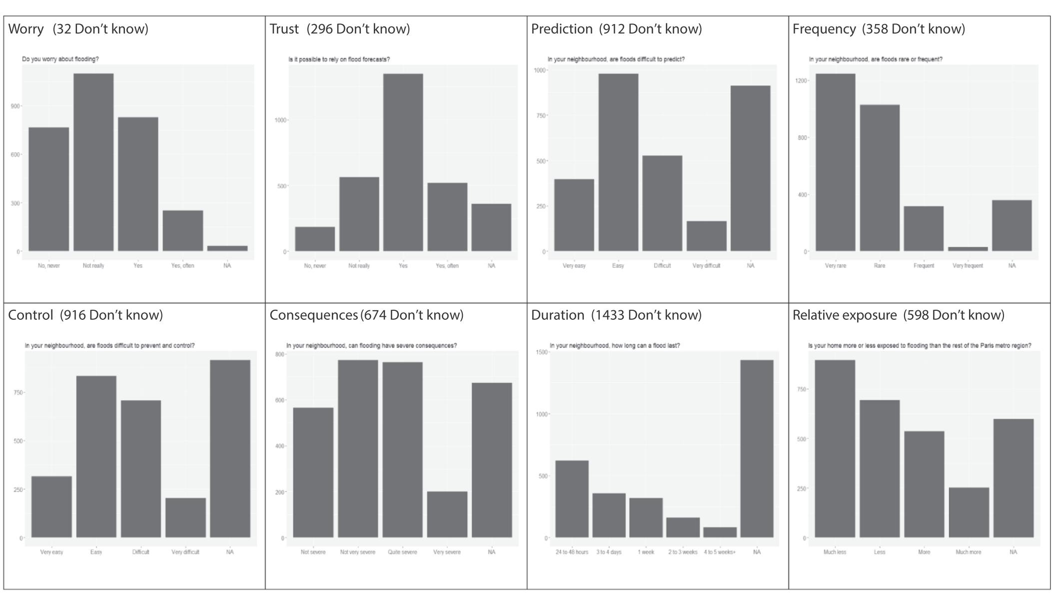

Fig. 1. Answers to the flood risk perception questions.

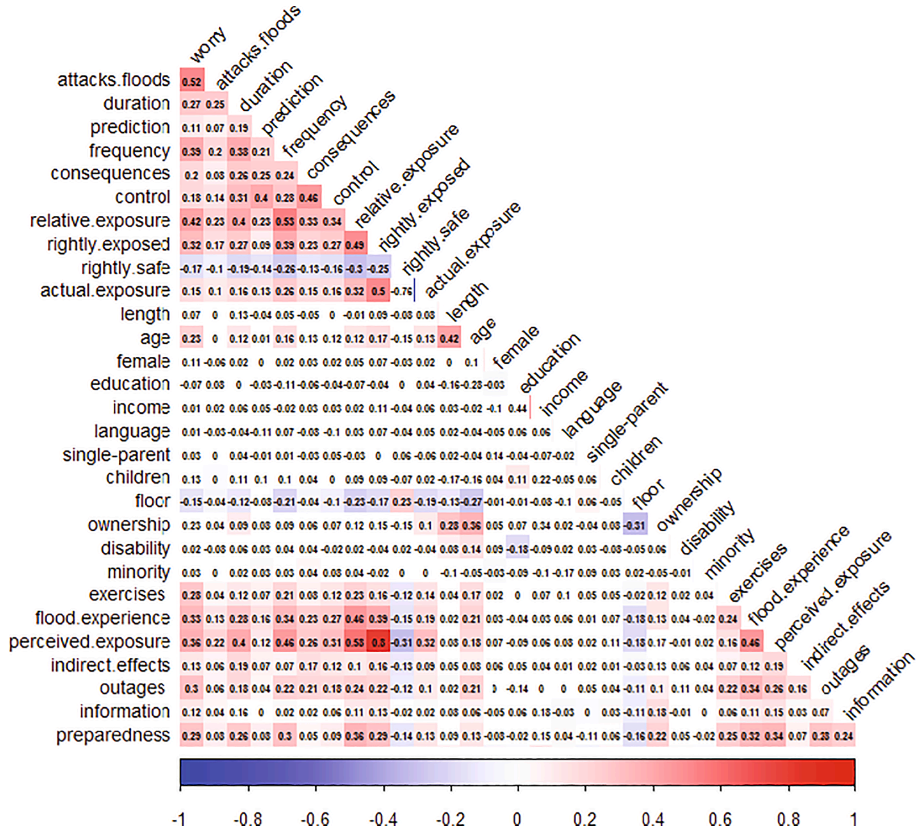

Fig. 2. Heatmap of the Pearson correlations among the variables.

awareness, for which we find consistent positive coefficient values, denoting that these variables increase flood risk perceptions. Respondents with previous flood experience are more likely to have a higher level of worry, and they believe that floods are difficult to control and predict. They also have a high perceived frequency, duration, and relative exposure to flood (supporting H1a). This effect on worry is also observed for the past experience of power outages caused by floods (supporting H1b).

Some support exists for our hypotheses about the relationship between risk perceptions and official risks. Compared with respondents who live outside a flood-prone area, those who live within the official delineation exhibit a higher level of worry for flooding; however, they believe that floods are more difficult to prevent and control, are more frequent, and are characterised by a longer duration, and demonstrate a higher likelihood to answer that their homes are relatively more exposed to flooding. These findings support H2a for five out of eight dimensions, and they are consistent with the studies mentioned in Section 3. Furthermore, H2b about respondents who live on higher floors and have lower risk perceptions are similarly supported for four dimensions, namely perceived flood frequency, ease of prediction, flood duration, and perceived relative exposure to flooding.

Support for H3a is even stronger, as awareness of living in a flood-prone area significantly influences all the risk perception dimensions, except in cases where respondents easily think that floods can be predicted. These results highlight the importance of making people aware that they live in a flood-prone area, as this knowledge appears to raise a broad range of risk perception dimensions. Support for the related H3b is weaker because we find a significant positive effect of living in an indirect effects flood zone, but only for the perceptions of flood duration and relative flood exposure.

General knowledge about the official flood risk information did not have a significant effect on any of the risk perception dimensions (rejecting H4a), which casts doubt on the effectiveness of flood risk communication strategies. Respondents with a memory of the previous flood exercises have a higher level of worry for flooding (supporting H4b), whereas those with a higher self-reported flood preparedness have a higher level of worry for flooding, a higher perceived flood frequency, and a likelihood to have a high perceived relative exposure to flooding (supporting H4c). Nonetheless, the causality of this effect is unclear, as high flood risk perception may result from preparedness.

5.3.2. Results of socio-demographic control variables

Fewer significant relationships are observed with socio-demographic and residence characteristics, sometimes with opposite effects from one flood risk dimension to another. Gender has no significant effect on flood risk perceptions, which is contrary to our expectation (Control variables 1). We find that worry for flooding increases with age, which is consistent with our expectation (Control variables 2), but this effect of age is insignificant for the other dimensions of flood risk perception. The results for Control variables 3 depend on the considered dimension, as respondents with more children and a low income have higher level of worry for flooding. This result is consistent with our expectation but contrary to our expectation that homeowners have higher perceptions of flood consequences. Evidence for education is mixed: less educated people exhibit a lower trust in flood forecasts, which is consistent with our expectation; however, they believe that floods are easier to control and characterised by a shorter duration. We also found mixed results for the length of residence. Respondents who lived for a longer period in the neighbourhood perceive a lower flood frequency and relative exposure, which is consistent with our expectation (Control variables 4), but they also anticipate a longer duration of flood events.

5.3.3. Results of models relative to terrorist attacks and of correctness about being exposed to floods

Having a higher level of worry for flooding than for terrorist attacks is positively related to actual risk and awareness of living in a flood-

Table 2
Models of flood risk perceptions with all the explanatory variables. *Final regression results based on a stepwise backward selection approach (18 models, 18 variables).*

	levelsofworry	*levelsoftrust*	*levelsofcontrol*	*levelsoffrequency*	*levelsofconsequences*	*levelsofprediction*	*levelsofduration*	*levelsofexposure*	*floodsvsattacks*	*rightlyexposed1*	*rightlyexposed2*	*rightlysafe*	*don'tknowcontrol*	*don'tknowfrequency*	*don'tknowconsequences*	*don'tknowprediction*	*don'tknowduration*	*don'tknowexposure*
(Intercept)	0.477***	0.957***	0.797***	0.319***	0.658***	0.902***	0.516***	0.545***	0.571***	−3.980***	−2.001***	−1.958***	−0.143	0.699***	−0.197***	0.225	−0.098	−0.259
Previous XP	0.110*		0.099*	0.115*		0.074*	0.093*	0.142***		1.025***	0.629***	−0.717***	−0.492***		−0.420**	−0.322**	−0.605***	−0.273*
Outages	0.070**										0.166**	−0.273**	0.164*					
Actual risks	0.035*		0.061***	0.087***			0.053*	0.116***	0.015*	—	—	—	−0.178***		−0.181***	−0.116**	−0.079**	
Floor resid.				−0.033*		−0.022*	−0.025*	−0.033***	−0.011*	−0.101**	−0.107***	0.225***						−0.139***
Awareness	0.163***	0.073**	0.153***	0.245***	0.185***		0.348***	0.396***	0.162***	—	—	—					−0.443***	
Indirect effect					0.134***		0.069*			0.719***	—	−0.304**	−0.649***	−0.790***	−0.764***	−0.724***	−0.319***	−0.438***
Information														−0.772**	−0.442**	−0.504***	−0.375**	
Exercises	0.097*																	
Preparedness	0.061**			0.065**				0.050*		0.302***	0.180***	−0.227**	−0.147**		−0.193***	−0.147**	−0.157***	−0.402*
Female									−0.040*									
Age	0.024*										0.078**	−0.114*	−0.070**			−0.096***		
Education		0.012*	−0.024*					−0.023*							−0.063*	−0.071*		−0.074*
Income	−0.020*									0.070**			−0.083***	−0.144***		−0.082***		−0.065*
Ownership		0.056*			0.064**						0.247**							
Language						−0.085*	−0.158*			0.421*								
Single parent																		
Children 12	0.065**										0.139*							
Length resid.				−0.018*			0.035**	−0.019*		0.124**		0.096***		−0.192***	−0.054**			−0.102***
AIC	5233	5601	5195	4817	5709	5590	3624	4896	5755	1681	2919	2033	2653	1569	2773	2734	3315	2060
Deviance	568	533	501	395	712	591	614	520	567	959	1495	1265	1427	1047	1619	1442	1357	1280
Pseudo R^2	0.412	0.221	0.371	0.314	0.285	0.189	0.472	0.382	0.370	0.492	0.341	0.430	0.439	0.501	0.476	0.417	0.434	0.443
N	1784	2090	1727	1855	1887	1891	1169	1726	2128	2132	2416	2438	2235	2437	2724	2296	2184	2229

Signif. Codes: '***' 0.001 '**' 0.01 '*' 0.05 ' ' 0.1

prone area, whereas it is negatively related to being female. Overall, we observe a consistent pattern of variables influencing whether people are correct about being exposed to the direct (rightly exposed 1) or direct and indirect (rightly exposed 2) impacts of flood or correct about living in a safe area. Although the rightness of perceptions about living in the flood or indirect effect zones increases with age, the probability of being right about being safe increases with the length of residence and decreases with age. Previous experience of floods and severe outages, preparedness, income, and language proficiency also increase the likelihood that respondents' perceptions about living in the flood zone are aligned with their actual exposure to floods. However, the floor of residence has an opposite effect. Living on higher floors probably offers a false sense of safety. The negative relationship of previous flood experiences and severe outages along with self-reported preparedness on being rightly safe make sense: previous experience of adverse consequences from floods and preparedness for floods might prevent respondents from feeling safe, even though they presently live outside the official flood zone.

5.3.4. Results of models about the ability to answer risk perception questions

Overall, we find that the same significant predictors have a symmetric impact on the answers to the flood risk perception questions and the ability to answer these questions. This implies that most of the variables that explain higher risk perceptions also explain why people have answered the question in the first place. However, some sociodemographic characteristics have more significant effects on the failure to give an estimate than on answers to the perception questions, especially age, education, and income. This finding suggests an implicit selection effect in studies that treat 'don't know' or nonresponses as missing observations: flood risk perceptions are expressed by significantly older, richer, and more educated people. People who are unable to answer are often eliminated in previous studies; hence, such factors might wrongly appear to have no impact on flood risk perceptions. The influence of risk information is worth noting: although it has no significant relationships with expressed risk perceptions or even being rightly exposed or safe—which is, nonetheless, its primary objective—it has an almost systematic negative impact on failing to give an estimate. In other words, risk information positively affects the likelihood to answer flood risk perception questions. People who are unaware of official risk information more likely fail to give an estimate, thereby suggesting their lack of knowledge about the dimension of flood risk inquired. Furthermore, respondents failing to answer the questions on floods face a lower flood risk, have been living in the neighbourhood for a shorter period, are younger, and/or have less first-hand flood experience, and all of these factors might reflect rational behaviour. These respondents have less at stake and have fewer reasons and less time to acquire information on flood risks. This aspect may explain why they have less knowledge on the various dimensions of flood risks, thus reducing their ability to answer the risk perception questions.

6. Discussion

6.1. Discussion of the results in relation to the existing literature

The results of Table 2 in relation to our hypotheses and expectations for control variables are summarised Table 3. In summary, the hypotheses supported by the largest number of dimensions are H3a on the awareness of living in a flood-prone area (7 out of 8), H1a on previous flood experience (6), and H2a on living in a flood zone (5). Moreover, most effects of our control variables on social vulnerability matched our expectations (5). The dimensions that most frequently and expectedly relate to explanatory variables are the worry about floods (8 out of 13), perceived exposure (7), perceptions of flood frequency (6), and duration (6). Although worry is the perception dimension most often used in previous studies and one that supports most of the hypotheses in our own results, using that single criterion would cause the rejection of some hypotheses (H2b, H3b) that are nevertheless supported for several other dimensions.

The importance of flood experience in shaping flood risk perceptions

Table 3
Summary of results in relation to our theoretical hypotheses and expectations for control variables.

		worry	trust	control	frequency	consequences	prediction	duration	exposure	*total*
H1a	*Respondents with flood experience have higher perceptions of flood risk.*	+		+	+		+	+	+	*6*
H1b	*Respondents with severe outage experiences after a flood event have a higher awareness of the flood's indirect effects.*	+								*1*
H2a	*Respondents who live in an area with a higher flood risk have higher flood risk perceptions than those who live in an area with a lower flood risk..*	+		+	+			+	+	*5*
H2b	*Respondents who live on higher floors have lower flood risk perceptions than those who live on lower floors (or single-family homes).*				+		+	+	+	*4*
H3a	*Respondents who are aware that they live in a flood-prone area have higher flood risk perceptions than those who are unaware of this situation.*	+	+	+	+	+		+	+	*7*
H3b	*Respondents who are aware that they live in an indirect effect zone have higher flood risk perceptions than those who are unaware of this situation.*					+		+		*2*
H4a	*Respondents with knowledge of official flood risk communication have higher perceptions of flood risk.*									*0*
H4b	*Respondents with the memory of previous flood exercises have higher perceptions of flood risk.*	+								*1*
H4c	*Respondents with higher self-reported flood preparedness have higher perceptions of flood risk.*	+			+				+	*3*
CV1	*Male respondents have lower flood risk perceptions than female and minority respondents ('white male effect').*									*0*
CV2	*Older respondents have higher flood risk perceptions than younger respondents.*	+								*1*
CV3	*Respondents in socially vulnerable situations have higher flood risk perceptions than other respondents.*	+	–	+		–	+	+	+	*5* *−2*
CV4	*Respondents with more experience with living in a flood-prone area have lower perceptions of flood risk.*				+			–	+	*2* *−1*
	total	*8*	*1–1*	*4*	*6*	*2–1*	*3*	*6–1*	*7*	

points toward System 1 intuitive thinking about risks (Kahneman 2011a). In particular, this result supports the availability heuristic in influencing risk judgments (Tversky and Kahneman 1974). This finding confirms the suggestion in the previous literature that individuals who have recently experienced a flood may find the scenario of a flood recurrence easier to imagine (Keller et al. 2006; Siegrist and Gutscher 2006; Botzen et al. 2015). Our assessment of the availability heuristic for the various dimensions of flood risk illustrates that flood experience positively influences the indicators for worry, control, prediction, duration, and exposure, but not trust and perceived consequences of flooding. This latter effect could arise when many respondents who experienced the flood event in the past did not suffer large consequences. Our findings also indicate that the direct experience of flood influences flood risk perceptions more than the effect of indirect consequences in the form of a power outage.

System 2 thinking processes also influenced flood risk perceptions (Kahneman 2011a) in our results, thereby expanding the findings of previous studies that observed a positive relationship between actual and perceived flood risks (Brilly and Polic 2005; Botzen et al. 2009; O'Neill et al. 2016) for the various dimensions of risk perceptions included in our analysis. This case especially applies to the awareness of living in an area with a flood risk that significantly influences 7 out of 8 dimensions of flood risk and living in a flood-prone area (five dimensions). According to Kellens et al. (2013), very few studies examined the influence of risk communication on flood risk perceptions. We find no significant effect of knowledge about official flood communication on the various perception dimensions. However, the memory of the flood exercise in Paris raised the worry about flood; furthermore, the flood preparedness stressed in the communication positively relates to worry, the perceived frequency of flooding, and perceived exposure.

Taken together, our results imply that both System 1 and System 2 thinking processes determine perceptions of flood risk in a combined manner for most risk perception dimensions. The only exceptions are trust and the perceived consequences of flooding, which are not influenced by the availability heuristic (System 1) but are shaped by the indicators of actual flood risk as per System 2 thinking. Our mixed results concerning the impact of socio-demographic characteristics are consistent with the conclusions of reviews of the flood risk perception literature (Bubeck et al. 2012; Lechowska 2018). Nevertheless, we observed several significant effects of these variables, notably for those that represent social vulnerability, which highlights the importance of including them as control variables in the analysis.

6.2. Discussion of the methods

The relevance of using regression analysis to estimate the independent effects of explanatory variables on risk perceptions becomes clear when the results from the simple correlation analyses (Fig. 1) are compared with the ones from the regression analyses (Table 2). As an illustration, the significant positive correlations of risk information with all flood perception dimensions appear misleading when controlling all the explanatory factors. By contrast, the lack of correlation between the socio-demographic variables and risk perception is obfuscating their effects that are observed in the regression analysis as well as their influence on the ability of certain respondents to answer the risk perception questions. Previous mixed findings reported in the literature may be partly caused by the large diversity of statistical methods employed in this literature, including correlation analyses and several selection biases.

When regression analyses are applied, the independent effects of explanatory variables appear to largely depend on the selection of control variables. This case becomes clear from a results comparison based on the subgroups of variables reported in Supplementary Tables 5–8, with the results including all the significant explanatory variables in Table 2. The self-fulfilling impact of selecting one explanatory framework over another is particularly striking, as solely controlling for the experience and knowledge variables results in reporting more significant relationships in support of the hypotheses driving such a choice. For instance, Supplementary Tables 5 and 6 show that knowledge of official risk information has a positive impact on at least one risk perception dimension (duration), awareness of indirect effects has a positive significant relationship with one more dimension (control), and previous experience has much stronger and consistent effects across all eight dimensions than in the final results (Table 2). The same case is true when choosing to only control for residential and socio-demographic drivers over this competing set of explanations. Supplementary Tables 7 and 8 show that single-headed households are found to have a positive impact on two risk perception dimensions (worry, duration), whereas age (trust, frequency) and children (duration) have positive significant relationships with more dimensions than in Table 2. By contrast, education (consequences, prediction) and floor of the residence (worry, control) have negative significant relationships with more dimensions. Different choices, as often made in previous studies, tend to yield confirmatory results.

Such a self-fulfilling selection effect is further complicated by the impact of choosing some risk perception dimensions over the others, as the criterion most in use in previous studies (worry about flood) would cause the rejection of some hypotheses that are otherwise supported for several other dimensions.

6.3. Discussion of the implicit selection bias

A more fundamental lesson of our study is the identification of the implicit selection bias of treating 'don't know' answers or nonresponses as missing observations, which was disregarded in the previous literature. Although the varying rate of respondents answering the 'don't know' option to different risk perception questions is an indication of fluctuating levels of knowledge about flood risk, the selective response behaviour might also be linked to attrition, mistrust, underprivilege, or disregard. Although the proportion of 'don't know' answers has no relation to the order of the questions, we believe that attrition is not a concern. The question on income had a response rate similar to previous studies – approximately one-third of the respondents declined to answer; meanwhile, the questions on trust garnered a high proportion of responses. Therefore, mistrust is an unsuitable explanation. We observed that actual risks have an impact by increasing the probability to answer some specific risk questions; thus, disregard or the feeling of being unaffected might be considered to play a role. However, we believe that a lack of knowledge about the particular dimensions of flood risk is a more logical explanation for the nonresponses. The easier questions on concern and worry over floods obtained answers from almost all respondents, whereas more technical questions on flood duration or predictability were only answered by roughly half of them. Furthermore, knowledge about the official flood risk information, awareness of direct and indirect flood impacts, along with previous flood experience, age, income, and education, all independently increased the ability to give estimates to specific flood perception questions. Younger, less experienced, less educated, and/or less privileged respondents are arguably more hesitant or concerned about giving a wrong answer. The fact remains that they express a knowledge gap. Finally, we interpret them as respondents who do not know how to answer or who exhibit less confidence in giving an estimate to a specific question on floods. More importantly, sample size and design are critical in allowing the exploration of the factors of influence on 'don't know' answers instead of discarding them as missing observations as is often performed in the literature. The novelty of our approach is allowing for the analysis of why a subgroup is unable to give an estimate to specific flood risk perception questions, which offers three main insights.

First, respondents with high official risk, high awareness, and flood experience are more likely to answer risk perception questions. Although we find that the awareness of indirect consequences from flooding is only significantly related to two risk perception dimensions, this variable has a significant effect on the ability to answer all the risk perception questions. This inference denotes that if one would only estimate statistical models for those people who can answer risk perception questions, then a conclusion can be mistakenly drawn that awareness of indirect consequences is unimportant in shaping risk perceptions; by contrast, our additional analyses reveal that this variable plays a role in the respondents' ability to answer flood risk perception questions.

Second, general knowledge about the official flood risk information appears to have a significant influence on the ability to answer flood risk perception questions. In particular, respondents with this knowledge are less likely to fail in answering questions about the perceived flood frequency, consequences, duration, and relative exposure. This implies that although the memory of the last campaign has not affected the levels of the flood risk perception and the last exercise only affected worry about floods, they reduced the people's unawareness of the many characteristics of flood risk as reflected in their inability to answer these questions.

Third, for some socio-demographic characteristics, we found more systematic relationships with the ability to answer the flood risk perception questions than with the level of risk perceptions. For example, low income only reduces the level of worry in a significant manner, despite a higher likelihood that low-income people are unable to answer questions related to the controllability, frequency, and predictability of flooding. Overall, we found that flood risk perceptions are expressed by significantly older, richer, and more educated people. Thus, previous studies discarding 'don't know' answers or nonresponses might implicitly deem younger, poorer, and less educated respondents as out of scope and wrongly infer that such characteristics have no impact on flood risk perceptions. In association with the diversity of methods and self-fulfilling choices applied in the flood risk perception literature, such an influential and implicit selection bias may explain the mixed findings and contradictory results reported thus far.

6.4. Lessons for flood risk communication strategies

In France, in compliance with the European flood directive, Basin Flood Risk Management Plans (FRM) are to be updated every six years since 2015; furthermore, directly impacted municipalities are required to hold a public information meeting every six years (Barraqué 2017). Since 2006, the mandatory buyer–tenant information (IAL) requires informing new occupants (once) of their direct exposure to natural and technological hazards to enable them to adapt their homes accordingly (Mauroux 2018). Although much more flood risk information is made available (regional and national websites, flood markers, local plans), the responsibility for accessing it is being delegated to private parties, as residents must ensure that they are informed about these risks (Fournier et al. 2018). At the local level, no uniform risk communication strategy exists between municipalities; for example, Paris organised an annual event for some schools along the Seine River in the past decade. Overall, no information on indirect effects from floods is available, and people living outside the direct flood zone are deemed to be beyond of the scope of communication policies.

Two years after the EU flood simulation was conducted in 2016 to raise awareness of flood risk, and despite the 2016 and 2018 subsequent floods, we found that only one-third of the respondents who were directly exposed to floods rightly perceived themselves as living in the flood zone, and more than half of those living in the indirect effect zone wrongly perceived themselves to be safe. Our results confirm that neither the widespread commemoration of the centenary of the major flood in Paris in 1910 nor the current risk information provision is sufficient to increase flood risk perceptions (Baubion 2015). The reason is that knowledge of risk information had no significant effect on flood risk perceptions, and the memory of the last exercise only affected worry about floods. Despite these findings, flood risk communication was not useless because it enabled respondents to form an idea about various dimensions of flood risks and significantly influenced the ability to answer the perception questions. This evidence is only noticeable by exploring why a subgroup is unable to answer or less confident in giving an estimate. In other words, discarding 'don't know' answers as missing observations might give the inadequate impression that risk communication does not have any effect on flood risk perception.

Nevertheless, the need for improving risk communication strategies is clear, as our results also indicate that many individuals misperceive the flood risk they face. This is surprising as two salient flood events occurred and a flood simulation was organised over the course of just the previous two years, each receiving international coverage for days. The last floods arguably failed to trigger strong enough feelings or that the EU flood simulation was disregarded despite the media coverage. However, it is quite challenging for a risk communication strategy to be more effective than the impact of an actual disaster. Previous studies have consistently indicated that the memory of past disasters promptly fades over time (Bin and Landry 2013). As three major events of the two previous years were insufficient to raise awareness about flood risk in Paris, we observed that communicating about flood risk every two years is relatively infrequent. The risk information provisions in Paris are presently operating on a less frequent basis.

Based on our findings, we suggest that flood risk communication policies can be improved by increasing the frequency of risk communication campaigns, for example, to annually or more often. Flood risk information policy that merely aims to increase worry or fear might be at risk of backfiring. Hence, we propose that the content of such campaigns should focus on raising flood awareness and improving information provision about the direct and indirect flood risks that people confront. Our results suggest that these factors are some of the main drivers of various dimensions of flood risk perceptions. Regular communication strategies should endeavour to keep the memory of past floods alive, as the availability heuristic appears to play a major role in shaping risk perceptions. An advisable approach is to particularly target the people who are presently unable to give flood risk estimates and/or unaware of their exposure to floods, including vulnerable individuals, renters, newcomers, younger people, and individuals lacking previous experiences with floods and their indirect effects. We also recommend extending the focus of flood risk information from residents directly exposed to all those indirectly exposed to floods impacts. For this purpose, FRM plans should include an external zone with all municipalities that can be indirectly affected.

7. Conclusion

Flood damages have been increasing around the world, and they are expected to continue to rise because of climate change and growth in exposure in flood-prone areas. To reverse this trend, a sufficient degree of awareness of flood risk among the population is required to support flood risk management policies and improve flood preparedness. However, empirical studies on the drivers of flood risk perceptions conducted thus far derive mixed and contradictory results, thereby hampering the understanding of why awareness about flood risk is often low and complicating the design of flood risk communication policies. This study explored the various dimensions of flood risk perceptions and their drivers to draw lessons for guiding flood risk communication strategies.

We tested a variety of hypotheses about the variables of influence on flood risk perception and various dimensions that are motivated by a theoretical framework of System 1 and System 2 thinking about risks. Our survey answered by a representative sample of 2,976 households allows for the examination of the role of past flood experiences to test the availability heuristic (System 1) and indicators of actual risk and communication campaigns (System 2) in shaping perceptions. Our results imply that System 1 and System 2 thinking processes determine the perceptions of flood risk in a combined manner. Relative to most of the risk perception dimensions, we observe significant relationships with variables representing both of these systems.

The novelty of our approach is that the large sample facilitates the analysis of why a subgroup is unable to give an estimate to specific flood risk perception questions, which has yet to be systematically studied. Overall, flood risk perceptions are expressed by significantly older, richer, and more educated people, and respondents who fail to answer the questions on floods also tend to face a lower flood risk, have been living in the neighbourhood for a shorter period, and/or have less first-hand flood experience. Such selective response behaviour suggests that some people have insufficient knowledge about the particular dimensions of flood risk inquired. We offer new insights into the role that information campaigns and social vulnerability play in the ability to answer the questions. We prove that findings are highly dependent on the choice to either analyse why a subgroup is unable to give an estimate to specific flood questions as conducted in our study, or conversely discard 'don't know' answers as missing observations as has been conducted in previous research. We conclude that previous studies implicitly treating 'don't know' answers or nonresponses as missing observations might be biased by a selection effect.

In addition to such an implicit selection bias, our results reveal that the findings are highly dependent on other more explicit choices, including the self-fulfilling impact of choosing one explanatory framework over another, the applied methods of analysis, and included control variables, along with the selection of one or more risk perception dimensions. Future research should discuss such choices in a more systematic manner, as they might explain the mixed findings and contradictions on flood perception drivers reported in the literature.

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CRediT authorship contribution statement

Samuel Rufat: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **W. J. Wouter Botzen:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

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

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