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ORIGINAL ARTICLE

Risk tolerance as a complementary concept to risk perception of natural hazards: A conceptual review and application

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Abstract

There is a longstanding assumption that if people perceive a risk as high, they will act to reduce it. In fact, research has shown a lack of consistently strong causal relations between risk perception (RP) and mitigative behavior—the so-called "risk perception paradox." Despite a recent increase in research on RP, individuals' risk tolerance (RT; or demand for risk reduction) only rarely appears as a consideration for explaining behavioral response to natural hazards. To address this research gap, we first systematically review relevant literature and find that RT has been directly assessed or operationalized using perceived thresholds related to costs and benefits of risk reduction measures, risk consequences, hazard characteristics, behavioral responses, or affective reactions. It is either considered a component or a result of RP. We then use survey data of individuals' RP, RT, and behavioral intention to assess relations among these variables. Comparing across three European study sites, "behavioral intention" is assessed as the public's willingness to actively support the implementation of nature-based solutions to reduce disaster risk. A series of tests using regression models shows RT significantly explains variance in behavioral intention and significantly contributes additional explanatory power beyond RP in all three sites. In two sites, RT is also a significant partial mediator of the relation between RP and behavior. Taken together, our findings demand further conceptual and empirical research on individuals' RT and its systematic consideration as a determinant for (in)action in response to natural hazards.

KEYWORDS
disaster risk reduction, public perception, risk acceptance, risk perception, threat response

1 | INTRODUCTION

Understanding how people respond to rapidly changing risks from natural hazards, in part due to climate change, is crucial for policy and practice that effectively communicates to the public and ultimately reduces negative impacts (Fischhoff, 2011; Pidgeon, 1998). Knowledge of individual risk perception (RP) can reveal how and why people make decisions in response to risk, along with helping to resolve public-expert conflicts, improving risk communication, and increasing the success of stakeholder outreach in disaster risk reduction (DRR) projects (Gough, 1990). Specifically, RP is related to individuals' demand for risk mitigation (Renn, 1998b). Such demand is one way to understand "risk tolerance" (RT), a concept that we aim to explore in relation to RP and natural hazards in this paper. To do this, we first describe foundational research on the concepts of RP and RT and their relation.

RP is often used to predict risk-reducing behavior to prepare for, cope with, or recover from disasters. Examples of "threat response" behavior or behavioral intention are broad, can lead to private and/or public benefits, and range from seeking information (Altarawneh et al., 2018; Terpstra, 2011), purchasing insurance, flood-proofing homes (Aerts et al., 2018; Bubeck, Botzen, Suu, & Aerts, 2012), support for legislation (Fischhoff et al., 1978), evacuation (Favereau et al., 2020), and collective action or public engagement with DDR measures (Altarawneh et al., 2018; Anderson et al., 2022). Mostly, a higher RP increases motivation for reducing risk and engaging in actual risk-reducing behavior. However, the causal strength of RP depends on context (Rufat et al., 2020; Wachinger et al., 2013), and different measures of RP have been found to relate in distinct ways to the demand for risk reduction (Rundmo & Nordfjærn, 2013; Sjöberg, 1999). While there is no standardized measure of RP in research on natural hazards and behavioral response (Rufat et al., 2020), the broader field generally agrees that measures of both cognitive appraisal (e.g., probability, severity) and affect (e.g., concern, worry, fear, anxiety) are useful (Breakwell, 2007). Wilson et al. (2019) suggest that capturing probability, consequences, and affect is the most "complete and theoretically accurate manner" (p. 781) to assess RP. Consequences (or impacts) of natural hazards, in particular, have been found to be greater determinants of risk mitigation behavior or behavioral intention than more traditional probability-based measures of RP (Bubeck, Botzen, & Aerts, 2012). Nevertheless, the so-called "risk perception paradox," that is, the persistent lack of evidence to consistently causally link higher RP of natural hazards with risk mitigation behavior (Wachinger et al., 2013), remains largely unresolved.

One suggested cause behind the RP paradox is the neglect of the concept of RT (also referred to as *risk acceptance*; Favereau, Robledo, & Bull, 2018) since individuals may "understand the risk but choose to accept it due to […] perceived benefits" (Wachinger et al., 2013, p. 1054) or because it is perceived to be beyond their control (Henrich et al., 2018). Closely related to RP, the concept is defined by Fischhoff et al. (1978) as the "[risk] level which is 'good enough', where 'good enough' means that you think the advantages of increased safety are not worth the costs of reducing risk…" (p. 132). When describing past research, we defer to the authors' terminology. Otherwise, we use RT instead of risk acceptance since risks are unlikely to ever be truly "accepted" in the general meaning of the word (Sjöberg, 1999) and because the latter has also been used in the context of "risk acknowledgment" (e.g., Paton & Buergelt, 2019). For example, Paton et al. (2017) strive to increase the "risk acceptance" of tsunami risk warnings—that is, increase awareness of the risk so that action can be taken.

RT as a concept is well-established within research that uses probabilistic risk analysis or economic methods, for example, safety engineering (Cha & Ellingwood, 2014), research on finance and investing (how much money one is willing to risk losing; Hallahan et al., 2004), and public health (smoking, driving, condom use, willingness to be vaccinated during a pandemic) (Du et al., 2017; Siegrist et al., 2021). Research on RT related to natural hazards has most commonly been the subject of technical studies that assess societal thresholds for injuries or death, for example, as a result of infrastructure failure (Cha & Ellingwood, 2014; Enright, 2015). These studies deal with "real," "objective," "statistical," or "predicted" risk rather than perceived risk and tend to rely on revealed or implied societal preferences (Gough, 1990).

However, like RP, the concept of RT has been explored within the psychological tradition of risk research (Renn, 1998a; Slovic et al., 1985) and has been found to vary substantially among individuals—often contradicting "revealed" societal thresholds (i.e., risk of death per person per year; Fell, 1993; Strouth & McDougall, 2022). This strand of RT research focuses on individual RPs with stated preferences (i.e., asking study participants), and how differing degrees of tolerance may determine mitigative behavior (Fischhoff et al., 1978; Gough, 1990; Sjöberg, 1999). In *Social Benefit versus Technological Risk*, Starr (1969) asks the question of "How safe is safe enough?" to determine what are claimed to be widely applicable thresholds of risk acceptance by considering the economic benefit versus the risk of death for a range of hazards. Starr (1969) found that, based on fatalities by hours of exposure, voluntary risks (e.g., smoking) are roughly 1000 times more acceptable than involuntary risks (e.g., "natural disasters"), and risk acceptance is roughly proportional to the third power of the benefits.

Fischhoff et al. (1978) returned to Starr's question but used psychometric survey methods to determine quantitative judgments of risk-benefit trade-offs of 30 different activities and technologies. They found that preferences varied greatly and suggested a divergence from established regulatory risk thresholds. The theory of risk homeostasis, proposed by Wilde (1982), advanced RT research by suggesting that there is a target level of risk desirable to individuals, and behavior may aim to bring perceived risk into equilibrium with this. Slovic et al. (1985) further established the relation between RP and RT. For RT, they used a Likert survey scale for the desired level of regulation of a range of hazards from "do nothing" to the greatest demand, "ban." In this early work, RT is often implied from relative RP of mostly socio-technical hazards (Gough, 1990).

More recently, Weber et al. (2002) created the Domain-specific Risk-Taking (DOSPERT) scale that promoted a wave of research considering "perceived-risk attitudes" (which includes the willingness to engage in a risky activity) in five common domains (i.e., contexts; ethical, financial, health, social, and recreational). Following other past RT research, the explicit consideration of benefits was central. It was found that while risk aversion was relatively consistent among individuals across risk domains, perceptions of benefits (and risks) of risky activities differed (Weber et al., 2002). In a follow-up study, Blais and Weber (2006) found that within-individual differences can be much greater across such domains, compared to differences among individuals. This supports the need for studying RP and RT within understudied domains.

One such domain lacking relevant research concerns individuals' RT in relation to natural hazards (Favereau et al., 2018; Peters-Guarin & Greiving, 2014). Authors have generally excluded hazards with "no benefit" from consideration (Alhakami & Slovic, 1994; Bronfman, Vázquez, Gutiérrez,

& Cifuentes, 2008; Sjöberg, 1999). Although natural hazards can sometimes provide benefits (e.g., recent droughts in Europe led to an archaeological bonanza in dried river beds), these are assumed to be negligible for predicting response. However, seeking benefits may involve "taking a risk" (Raue et al., 2018; Wachinger et al., 2013), and there is always a cost (money, time, effort, etc.) involved in actions to reduce risk (Eiser et al., 2012; Wilde, 1982). For example, risk may be tolerated from storms or landslides to enjoy the aesthetic benefits of beachside or steep-slope property (Anderson et al., 2022; Winter & Bromhead, 2012), and the cost of leaving things behind when evacuating before a hurricane may be perceived as too great (Weller et al., 2016). Thus, a risk might be tolerated up to a threshold for the benefit of avoiding a cost (Wilde, 1982). Along with risk homeostasis theory (Wilde, 1982), protection motivation theory (PMT) supports this position with its emphasis on response cost as a feature of coping appraisal (Rogers, 1975). Bubeck, Botzen, and Aerts (2012) describe response cost as "the person's estimate of how costly it would be for him or her to actually implement the particular risk-reduction measure" (p. 1485). PMT generally performs well at predicting risk response behavior (Milne, Sheeran, & Orbell, 2000). In relation to flood response, for example, Grothmann and Reusswig (2006) used it to explain seeking information and carrying out structural changes to the home, and Babcicky and Seebauer (2019) explained variation in having an emergency household plan, flood insurance, and coordinating with neighbors.

A framework that explicitly includes RT is proposed based on findings in a review on public acceptance of nature-based solutions (NbS) for DDR by Anderson and Renaud (2021). Their results show that active behavioral support (i.e., "behavioral acceptance") is often crucial for the success of NbS for DDR and significantly more important than for traditional "gray" infrastructure measures to reduce risk (e.g., dams for flooding, ground anchors for landslide). By focusing on RP in relation to behavioral acceptance, they develop the "risk perception—measure acceptance model" or "RP-MAM." The RP-MAM is presented as a decision tree that includes four ordered questions, two relevant here—"(1) Is there a perceived risk?," and "(2) Is the level of risk intolerable?" In a follow-up study on the acceptance of NbS, Anderson et al. (2021) use correlation and regression to determine the influence of survey variables of risk, nature, and place perceptions on behavioral acceptance. Findings show some consistent significant correlations of measures of RP and RT with acceptance across three European study sites.

In a literature review on RP and RT of volcanic hazards, Favereau et al. (2018) support the suggested lack of research on individuals' perceptions of RT to natural hazards and the implications for risk reduction behavior. In another review, Winter and Bromhead (2012) conceptualize global variation in acceptable risk thresholds to landslides. They introduce a "willingness diagram" that shows where different DDR approaches fall at the nexus of stakeholders' willingness to accept risk, to pay, and to affect the environment. They place support for NbS (described as "vegetation [bioengineering]") as requiring moderate levels of risk acceptance and willingness to pay and low levels of willingness to affect the environment. However, there has not yet been a review on the topic considering the full range of natural hazards or behavioral responses nor has the relation between RP and RT been sufficiently explored.

We address these research gaps by first carrying out a systematic literature review on RT to explore instances in which it has been assessed in the context of individuals' perceptions of natural hazards. In the review, we focus on how RT has been operationalized in this context and its relation to the concept of RP. We subsequently test survey measures of RT in a recent DDR project, as described in Anderson et al. (2021), and consider their relation to RP for explaining behavioral intention to mitigate risk.

In this paper, we are guided by an overarching aim: to explore the use of RT as a concept for assessing and explaining individuals' risk-reducing behavior to natural hazards. To achieve this, two research questions correspond with each of the primary methods (review and empirical testing):

RQ1: How have past studies conceptualized individuals' RT to natural hazards?

RQ2: How do survey measures of RT perform in relation to measures of RP for explaining individuals' intention to actively support NbS for DDR measures?

2 | METHODS

2.1 | RT review (RQ1)

To answer the first research question, we conduct a systematic review using the Web of Science database and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards for systematic reviews (Page et al., 2021) on applications of RT in relation to natural hazards. We create a keyword sequence in the Web of Science database by taking terms from foundational research on RT described in the introduction and combining these with terms to capture natural hazards (Table 1, full query in Supporting Information Text S1).

To screen the 418 articles returned by the search, we use the following criteria:

1. Articles must include a consideration of natural hazards (i.e., not just socio-environmental hazards such as air pollution or socio-technical hazards such as power outages).
2. The concept of RT must be applied (i.e., actively elicited, not just mentioned in the introduction or discussion) and be directly linked to the natural hazard.
3. Study methods must be carried out at the level of individuals' perceptions.

Criteria 1 and 2 exclude bodies of research within the broader field of RP (and RT). The first criterion excludes articles that assess RT to climate change that do not

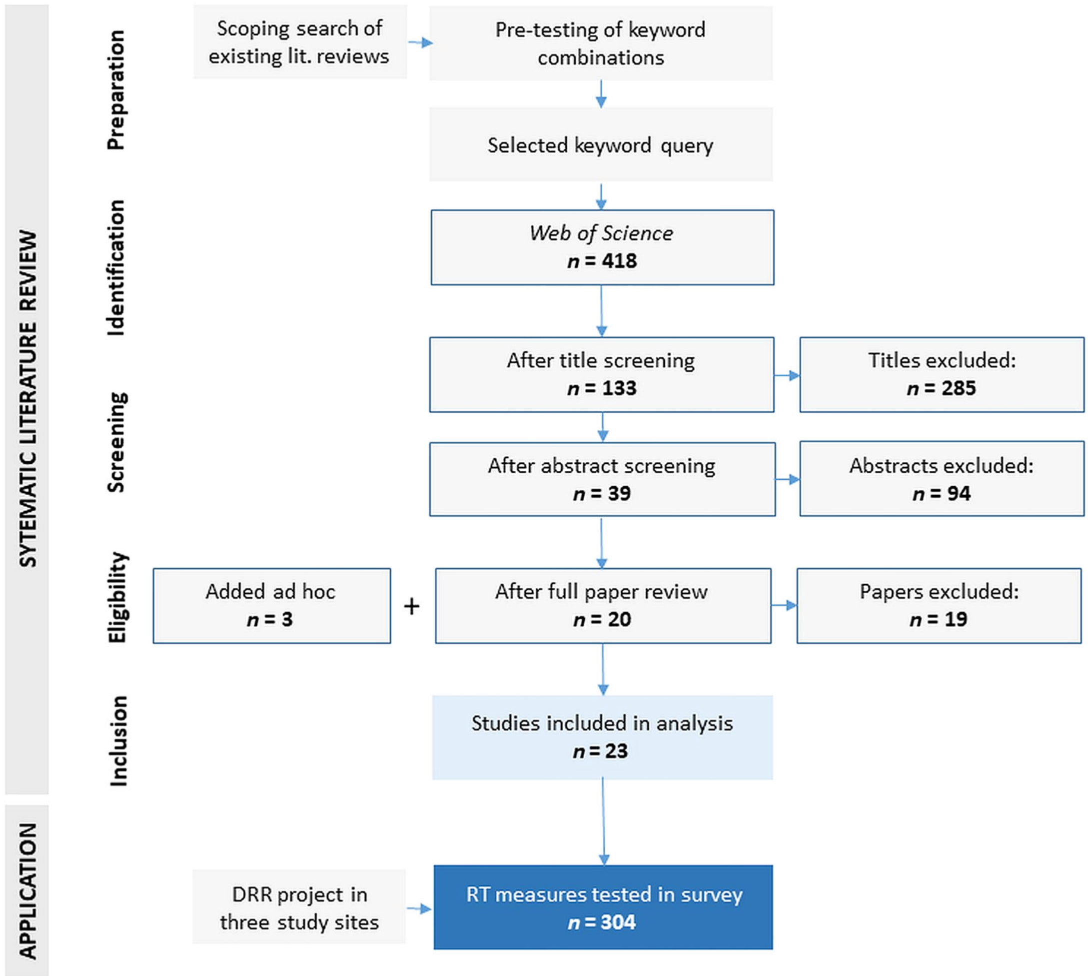

FIGURE 1 Flowchart of steps in the systematic literature review. We then test risk tolerance (RT) measures with application in a survey across three nature-based solutions (NbS) for disaster risk reduction (DRR) study sites with a total of $n = 304$ respondents.

TABLE 1 Variables and keywords used in systematic literature review query

Variable	Keywords
Risk tolerance (RT) *(in title, abstract or keywords)*	"risk *toleran*" OR "tolerated risk*" OR "risk *accepta*" OR "accepted risk*" OR "*tolerance to risk*" OR "risk threshold*" OR "risk propensity" OR "risk adjustment*" OR "target risk level*" OR "maximum risk*" OR "perceived threshold*" OR "satisficing thresholds" OR "cognitive threshold* OR "risk avoidan*" OR "risk perception threshold*"
Natural hazard *(in title, abstract or keywords)*	"natural hazard*" OR "disaster*" OR "extreme event*" OR "extreme weather event*" OR "natural risk*" OR "climat* risk*" OR "environmental risk*" OR "flood*" OR "avalanche*" OR "coastal erosion" OR "drought*" OR "extreme temperature*" OR "earthquake*" OR "extreme heat" OR "extreme cold" OR "eutrophication" OR "alg* bloom*" OR "*storm*" OR "hurricane*" OR "cyclon*" OR "typhoon*" OR "monsoon*" OR "landslide*" OR "mass land movement*" OR "frost" OR "hail" OR "lightning" OR "strong wind*" OR "tidal surge" OR "tornado*" OR "tsunami*" OR "wildfire*" OR "sea-level rise"

The search was carried out on September 10, 2022. We specified no year restriction, but the earliest article returned was from 1997. Following the steps in Figure 1, we included 23 empirical studies in the analysis. These cover 16 study site countries (plus one global study), most of which are in the Global North.

directly refer to the role of natural hazards. Despite some obvious overlap, distinct characteristics of climate change contribute to distinct perceptions, compared to more concrete and temporally and spatially salient natural hazard events (Gifford, 2011; Whitmarsh et al., 2021). The second criterion excludes studies that assess risk preference as a personal trait (i.e., risk-seeking or risk-avoidant). This excludes, for example, the well-established risk-elicitation task developed by Falk et al. (2022) in which respondents select either a probabilistic lottery or a sure payment, but the assessed risk preferences are not directly linked to any hazards. However, risk avoidance is a term sometimes used in relevant RT literature (hence included in our keywords).

Organization of the findings from the review follow the aim of this paper—that is, to determine the utility of the RT concept, also in relation to RP, for assessing individuals' perceptions of DDR measures and how these relate to risk-reducing behavior.

2.2 | RT application with survey data (RQ2)

2.2.1 | Survey design and data collection

Self-administered surveys were carried out at three rural study sites with residents at risk from hydrometeorological hazards within the context of the European Union's OPERANDUM project: Catterline, Scotland ($n = 66$ respondents); the Lake Puruvesi area in Eastern Finland ($n = 204$), and the Spercheios River Basin in Stereá Elláda, Central Greece ($n = 84$; Table 2; Anderson et al., 2021). Differences in physical and human geographical characteristics across the sites allow for a more robust testing of the variables (i.e., the "most different system" approach; Przeworksi & Teune, 1970). NbS with the primary aim of reducing risk were at the mature planning stage when the surveys were carried out between September 2019 and April 2020. The Covid-19 pandemic had not affected the study sites. Residents were aware of the ongoing project, and respondents were provided details on the project and NbS generally, described as natural measures that can reduce risk and provide additional benefits, at the beginning of the survey. Sampling approaches in the three sites aimed to maximize the total number of responses (Table S1).

2.2.2 | Survey variables

In this study, we assess five variables from the survey: three to capture dimensions of RP, two of RT, and a single dependent variable of behavioral acceptance. For RP, we consider hazard frequency (one item; "RP_frequency"), concern (one item; "RP_concern"), and consequence (summed scale of between 3 and 5 yes/no items regarding possible future impacts due to the natural hazard relevant to each site; "RP_consequence"). All variables use items of Likert 1–9 range in Catterline and Spercheios and 1–7 in Puruvesi (due to the limitation of online survey software used there), with the exception of the RP_consequence scale (summed yes/no binary items). For RT, we use a scale with items to assess indifference to risk at given thresholds of hazard and consequence based on the phrase "it is okay if," followed by "…[impact] occurs once every [frequency]," and a single item on demand for DDR at current risk level (i.e., "current levels of risk must be reduced"; Table 3A). These two variables are referred to as RT_scale and RT_demand. We take the inverse of RT_demand "risk must be reduced" so that it shares direc-

TABLE 2 Three European nature-based solution (NbS) study sites and their characteristics, including hazard type and primary NbS being implemented within the OPERANDUM project; adapted from Anderson et al. (2021)

Study site	Final *N*	Area	Hazard	Potential impacts	Primary NbS	Primary aim of NbS
Catterline	66	0.4 km^2	Landslide and surface erosion	Injury or death; damage to residential property, access roads; loss of recreation, aesthetics	Live cribwall, live grating, live pole drain	Slope protection and erosion control
Spercheios	84	92.4 km^2	River flooding and water scarcity	Injury or death; damage to residential and agricultural property, access roads; loss of recreation, livelihood	Natural water retention basins	Excess surface runoff storage and groundwater recharge
Puruvesi	204	73 km^2	Eutrophication and algal blooms	Negative human and animal health impacts; loss of tourism, fishing, aquatic recreation, aesthetics	Continuous cover forestry	Erosion control and reduction of runoff

Excel was used for data pre-processing, and further analyses were carried out using SPSS (v. 26). Single missing values for scale items were imputed using the median of other items for the same scale and respondent (Bernaards & Sijtsma, 2000). Additionally, "I don't know" responses on items in scales were treated as mid-point responses (see Table S2 for details of data imputation per item per site).

TABLE 3 Survey items and scales including their composition, calculation, and pre-processing steps RP_consequence is a scale composed of binary yes/no items summed together, while the RT_scale and behavioral acceptance (scale) are calculated using factor scores

(A) Items and scales used on the survey

	Independent variables (IV)					**Dependent variable (DV)**
Construct	**Risk perception (RP)**			**RT**		**Behavioral acceptance**
Variable	RP_frequency	RP_concern	RP_consequence	RT_scale	RT_demand	Behavioral acceptance (intention)
Item count	1	1	5–8	4–6	1	4–6
Item type	Likert[a]	Likert	Yes/no/I don't know	Likert	Likert	Likert
Aggregation method	N/A	N/A	Sum	Factor score	N/A	Factor score
Description	*[hazard] with negative impacts occur frequently in [site]*	*I am concerned about negative impacts from [hazard]*	*In the future, I believe [hazard] will affect my [exposed element; e.g., recreation, health, etc.] in [place]*	*It is okay if [exposed element] is/are affected by [hazard] once every [time span]*	*The current risk of negative impacts from [hazard] must be reduced*	*In the future, I would like to… [actions to support the NbS—implement, monitor, attend meetings, learn more, fundraise or source materials, other ways]*[3]

(B) Pre-processing steps for scales using factor scores

1. Compute Cronbach's α scores, α if item deleted and corrected-item-total correlations (CITC)
2. In parallel, run exploratory factor analysis (EFA) using principal axis factoring (100 iterations max), eigenvalues 1, and promax rotation (100 iterations max)
3. Remove items from each EFA model until the following criteria are met, in this general order of importance: α maximized; no CITC < 0.3; no communality < 0.3; no cross-loading factors, low loadings on all factors, or stand-alone large negative loadings; percent variance maximized; adequate KMO (Kaiser-Meyer-Olkin) test and Bartlett's test of Sphericity
4. Rerun this process iteratively, removing one variable at a time
5. Calculate weighted averages (non-refined factor score method) to use for further analysis

[a]Likert items had three anchors—*strongly disagree* (1), *neither agree nor disagree* (5), *strongly agree* (9). The Likert numbers given here correspond to the Catterline and Spercheios sites, where a 1–9 Likert range was used. In Puruvesi, a 1–7 range was used, and thus the anchors occur at 1, 4, 7.

tionality with the RT_scale variable (i.e., a higher response equates to greater tolerance, and therefore a hypothesized negative relation with RP and with behavioral acceptance).

The RP variables are inspired by key dimensions of RP summarized by Wilson et al. (2019): probability (RP_frequency), affect (RP_concern), and consequences (RP_consequence). Eliciting these dimensions follows the established practice of surveying perceptions of hazard characteristics (Fischhoff et al., 1978; Siegrist & Árvai, 2020; Slovic et al., 1985), concern about these characteristics (Gifford, 2011; Peters, Slovic, Hibbard, & Tusler, 2006; Rundmo, 2002; Terpstra, 2011), and their potential consequences (future impacts; Bubeck, Botzen, & Aerts, 2012). The RT variables are less established given the lack of past research in this context but are based first on foundational RT research regarding "how safe is safe enough" (Starr, 1969) and what risk level is "good enough" (Slovic et al., 1985). Inspiration is drawn from several other relevant studies and corresponds to findings from the literature review that follows (Buchecker et al., 2013; Finlay & Fell, 1997; Haynes et al., 2008; Maynard et al., 1976).

The dependent variable is a scale measure combining five Likert items to assess intention to support the NbS work (implement, monitor, attend meetings, learn more, fundraise or source materials, other ways; Table 3A). The inclusion of these items is slightly adapted to each site, designed with local project coordinators to represent actual behavior that the local residents could engage in to support the NbS. We refer to this variable as "behavioral acceptance," following Anderson et al. (2021). In this study, behavioral acceptance is thus the assessed threat response, although it is important to emphasize that we are assessing behavioral intention and not actual behavior (Sheeran, 2002).

We conduct tests of the validity of our measures for all variables with a focus on RT. For this, we assess Cronbach's α, corrected-item-total correlations, and exploratory factor analysis (EFA) using principal axis factoring (Table 3B). In the results, we also use descriptive statistics and Spearman correlation tables of all variables to further explore the RT construct and its relation to the other variables.

The variable RT_scale (with items using the phrase "It is okay if…") performs well in terms of internal consistency with α scores above 0.80 for all three sites and a single factor resulting from capturing most of the variance (Catterline: 72.60% variance explained, Cronbach's α 0.864; Spercheios: 62.29%, α 0.839; Puruvesi: 71.03%, α 0.854). We removed the item for "recreation" from the RT_scale variable for Spercheios since the factor analysis would not run with it included (a Heyward case was generated). Additionally, we removed the item "livelihood" from the Puruvesi scale because 182 of 205 total participants responded that they did not believe the eutrophication of the lake could affect their livelihood in the future. The behavioral acceptance dependent variable also performed well in this regard (Catterline: 75.83% variance explained, Cronbach's α 0.933; Puruvesi: 66.29%, α 0.898; Spercheios: 63.81%, α 0.856), and its validity was supported by respondents with high acceptance providing their contact information significantly more than respondents with low acceptance; Mann–Whitney U ($p < 0.05$; Anderson et al., 2021).

2.2.3 | Statistical methods and hypotheses

To answer the second research question (i.e., the performance of RT variables for explaining behavioral intention and their relation with RP variables), we run tests using regression models with behavioral acceptance as the dependent variable based on three ordered hypotheses:

H1: RP and RT will be significant predictors of behavioral acceptance.
H2: Adding RT to a model with RP will explain significantly more variance in behavioral acceptance.
H3: RT will significantly partially mediate the relation between RP and acceptance.

For H1, simple regression models are run with all RP and RT measures as independent variables ($n = 5$; three RP variables and two RT variables) for each of the three study sites (for 15 total models). Following this, we use the variable from each construct with the most explanatory power per site (i.e., the highest significant β) to test the subsequent hypotheses. Selecting the strongest variables for the subsequent models is justified given that the RP variables are established dimensions of the concept in the literature and may be more or less important to the respondents. Since RT is understudied, it is not clear what dimensions of the construct should be considered. However, this pre-selection must be considered for interpreting the relative strength of subsequent results.

For H2, stepwise regression models are run by starting with the strongest RP variable and adding the strongest RT variable from H1. The change in R-squared (R^2) is computed when adding the RT variable. If significant (based on an F-test), then the added variable contributes significantly to predicting behavioral acceptance *beyond (or despite) the predictive ability of RP*. In other words, if adding RT to a simple regression with only RP results in a significantly greater R^2, it suggests that RT is a separate and useful construct in this context.

For H3, mediation models are run using RT as a mediator between RP and behavioral acceptance (RP-RT-BA). This test is based on findings from the literature review, in which several authors argue that RP is antecedent to RT and there is a causal relation between them (i.e., higher RP causes lower RT) as well as in relation to behavioral response (Bronfman et al., 2015; Henrich et al., 2018). If RT significantly mediates the relation, this suggests that the utility of RP for predicting behavioral acceptance is meaningfully influenced by the construct of RT. We also run the mediation models with RP mediating the relation between RT and behavioral acceptance (RT-RP-BA). Comparing model outputs allows us to suggest whether the data may instead support this causal arrangement. We use the PROCESS macro for SPSS to test mediation[1] (Hayes, 2017).

3 | RESULTS

3.1 | Review: How have past studies conceptualized individuals' RT to natural hazards?

3.1.1 | Operationalizing RT

We group the different operationalizations of RT from the reviewed literature into five thematic and overlapping categories: RT is assessed based on the deliberation of costs and benefits, risk consequences, hazard characteristics, behavioral responses, affective reactions, or it is directly elicited (Table 4). In this last case, assumptions about RT are not made explicit, and respondents are directly asked questions such as "How acceptable is the risk?" (Bronfman et al., 2015). Depending on these approaches, RT can be measures of specific numeric thresholds (meters, deaths, frequency, score average, etc.); a range (e.g., money invested); a balance (e.g., costs-benefit ratio); a change in behavior (e.g., evacuating or not); or a change in affective state (e.g., worry, anxiety). In the articles relying on direct elicitation, RT was operationalized either as a yes/no respondent-defined threshold of acceptability or as a spectrum on a scale (e.g., 7-point Likert range of "*not at all acceptable*" to "*totally acceptable*").

Treating RT as a risk threshold or "target level" was common among the articles (Ahmed et al., 2018; Favereau et al., 2018; Tappenden, 2014) and some use this to distinguish "tolerable" from "acceptable" risk (Finlay & Fell, 1997; Peters-Guarin & Greiving, 2014). For example, Tappenden (2014) defines tolerable risk as the maximum risk people are willing to live with in exchange for perceived benefits, whereas acceptable risks refer to generally minor risks that do not require management. Finlay and Fell (1997) suggest that the difference between tolerable and acceptable risk may explain discrepancies in studies on societal risk thresholds based on revealed preferences and those exploring stated preferences. Specifically, they explain, tolerable risk is that which individuals may be prepared to live with, despite the risk being at a level that society treats as unacceptable.

Seventeen of the 23 empirical articles identified used surveys (Table S3), most of which included one or more items on a standardized scale to assess RT. Most studies assessed latent hazard risk, but in three studies, questionnaires were conducted soon after a disaster (Liu & Miao, 2018; Liu et al., 2019; Weller et al., 2016). Also, in two studies, two repeated measurements were used to assess changes in RT over time (Li et al., 2021) or after an intervention (i.e., participatory risk assessment; Buchecker et al., 2013). The second most common method was interviews (n = 8), followed by different participatory approaches (n = 5). In these, RT was either directly elicited (e.g., Tappenden, 2014) or interpreted in analysis (e.g., mental models in Findlater et al., 2019, and matched-pair design in Weller et al., 2016). Four articles used semi-experimental approaches—hypothetical hazard scenarios in questionnaires, contingent valuation, and framing experiments (Finlay & Fell, 1997; Markanday et al., 2022; Vinnell et al., 2016; Zhai & Ikeda, 2008). RT was most commonly researched in relation to flooding (n = 8), landslides (n = 7), storms (n = 7), and earthquakes (n = 6) while several articles assessed RT to natural hazards in comparison to other hazard types (e.g., technological, social, health; e.g., Bronfman et al., 2015, Henrich et al., 2018). Most studies do not rely on a behavioral theory and instead cite foundational psychometric RP studies. The exceptions are Ahmed et al. (2018), who use PMT, Buchecker et al. (2013) who compare modern portfolio theory and modern disaster theory, and the use of risk homeostasis theory in Favereau et al. (2018) and Favereau et al. (2020).

3.1.2 | Relationship between RP and RT

There is a general understanding among the articles that RP is related to RT, and only in a few exceptions was RP not mentioned at all (i.e., Liu & Miao, 2018; Thaler et al., 2022). The nature of the relationship, however, varies. RT is mostly either considered a component of a person's RP (Favereau et al., 2018; Plattner et al., 2006) or as an outcome of RP and thus a distinct concept (i.e., RT is predicted by RP; Bronfman et al., 2015; Eriksson, 2014; Huang et al., 2013). Henrich et al. (2018) take this perspective: "By establishing where a hazard scores with regard to various risk characteristics, researchers can enhance their predictions of how tolerant people are of a particular danger and how much regulation they desire for it" (p. 763). This is the traditional link between the concepts proposed (often implicitly) in foundational psychometric RP research (Fischhoff et al., 1978; Slovic et al., 1985). Favereau et al. (2018) refer to Wilde (1982) on risk homeostasis theory to distinguish RT from RP, considering RT as more central to decision-making since it "depends on the evaluation of costs and benefits of the different options that a person can take in the face of a risk" (p. 32). In summary, there is widespread agreement of a causal connection between RP and RT, as well as evidence of some discrepancy in the psychological mechanisms behind the constructs. We start with the assumption that RP influences RT, while also testing the inverse, in our empirical analysis with survey data in the following section.

Articles assessing both RP and RT mostly considered the constructs to be inversely related; that is, as RP increases, RT decreases (e.g., Buchecker et al., 2013; Markanday et al., 2022). According to risk homeostasis theory (Wilde, 1982) used in Favereau et al. (2018), action is taken to reconcile differences between RP and the desired "target level" of risk (i.e., RT). However, this perspective is nuanced in other articles by considerations of costs and benefits and competing risks (Buchecker et al., 2013; Findlater et al., 2019; Huang et al., 2013). This cost-benefit weighing reflects the dominant

[1] https://www.processmacro.org/index.html

TABLE 4 Thematic categories of how RT is conceptualized in the 23 reviewed articles. Articles can belong to multiple thematic categories by operationalizing RT in multiple ways in the same study. For a complete article-by-article table, including details regarding the outcomes investigated and key findings, see Supporting Information Table S3

Theme	Examples of operationalization	Methods
Balance of costs and benefits ($n = 11$)	• Degree of acceptability of probabilistic threshold of deaths per year compared to other everyday life risks and benefits (e.g., housing location; Tappenden, 2014) • Acceptable warning time and acceptable insurance premium (Liu & Miao, 2018) • Willingness to pay tax for risk-reducing actions (Henrich et al., 2018) • Acceptable expenditure in risk reduction to earthquakes given its relative risk, compared to other hazards (Vinnell et al., 2016)	• Questionnaires • Participatory risk assessment • System dynamics model and agent-based model • Interviews • Mental model mapping • Expert panel • Hypothetical scenarios • Framing experiment
Threshold of consequences ($n = 10$)	• Maximum acceptable probabilities of property damage and loss of life per year (Finlay & Fell, 1997) • Acceptable risk of dying (across society as a whole) as a consequence of a given hazard (Huang et al., 2010) • Acceptability of above- and below-floor inundation (Zhai & Ikeda, 2008)	• Questionnaires • Hypothetical scenarios • Semi-structured interviews • Participatory risk assessment • Contingent valuation
Direct elicitation ($n = 7$)	• "How acceptable is the risk?" (Bronfman et al., 2015, p. 313); "Do you think the risk is acceptable?" (Li et al., 2021, p. 3) • Degree of tolerance if risk is present in life or working surroundings (Huang et al., 2013) • Degree of need for risk reduction; whether flood protection for 300-year flood event is unnecessary (Buchecker et al., 2013)	• Questionnaire (scales) • Scenario planning, impact matrix ratings
Decision-making and behavior ($n = 7$)	• Thresholds for taking adaptive actions to flood risk (Ahmed et al., 2018) • Amount of money invested in protection from floods in experimental setting (Markanday et al., 2022) • Threshold for supporting legislation to reduce earthquake risk (Vinnell et al., 2016)	• Interviews • Rapid rural appraisal Framing experiment • Participatory risk assessment • Questionnaires
Threshold of hazard characteristics ($n = 6$)	• Degree of acceptability of agricultural land being flooded once in 10 years (Buchecker et al., 2013) • Acceptable distance between house/working place and the location of debris-flow disaster (Liu & Miao, 2018) • Acceptability of hazard frequencies ("Once every…"; Liu & Miao, 2018)	• Questionnaire • Contingent valuation • Public meeting • Interviews • Rapid rural appraisal
Affective reactions ($n = 5$)	• Hazard level at which people become "uncomfortable," "impatient," "unmanageable," "worried" (Ahmed et al., 2018) • Level of concern about the issue (earthquake-prone buildings) as part of the RT scale (Vinnell et al., 2016) • Levels of concern and pessimism regarding livelihood risks (Eriksson, 2014)	• Interviews • Questionnaires (scales) • Framing experiments

perspective in the reviewed articles and is used to distinguish RT from RP (Bronfman et al., 2015; Fischhoff, 2011). Bronfman et al. (2015) hypothesize that if, for example, earthquake risk is considered acceptable by survey participants, this implies that a consideration of benefits has occurred. Fischhoff (2011) shows that the benefits of risks are highly contextual and the same hazard may be tolerable in some situations and intolerable in others. A study by Eriksson (2014) of Swedish forest owners provides an example of benefits not being derived directly from the risk but from owning the forest. Similarly, Tappenden (2014) points out that despite there being no benefits from the risk (landslide), there are indeed benefits associated with housing location even when exposed to the hazard.

The review highlights several key gaps in the literature and confirms the suspected scarcity of articles explicitly on RT and behavioral response to natural hazards. In the articles reviewed, this is attributed largely to the benefits implied in risk decision-making being neglected. There also is a lack of consensus on how to measure RT or how to conceptualize it in relation to RP, and its impact on behavior. Several of the gaps we aim to address with empirical data were reinforced in the review: Few of the articles describe the individual contribution to physical DDR measures as a possible risk response; only Winter and Bromhead (2012) consider NbS in their theoretical commentary on RT, in which no empirical data were applied; and no research in the review empirically assesses the mediating effects of RT in relation to RP and intention to respond.

Using the available survey data for the empirical analysis that follows, our operationalization of RT as a cause of RP tests three of the thematic categories above (Table 4). The variable RT_scale (composed of items based on acceptance of impacts occurring at a certain frequency) is both based on a threshold of consequences and of hazard characteristics (similar to Buchecker et al., 2013), while our single item variable RT_demand is a direct elicitation of RT (Figure 2).

3.2 | Application

How do survey measures of RT perform in relation to measures of RP for explaining individuals' intention to actively support NbS for DDR measures?

3.2.1 | Survey variables

All three sites show significant low to moderate Spearman correlations between the two measures of RT (Catterline: $p = 0.544$, $p < 0.01$; Spercheios: $p = 0.259$, $p < 0.05$; Puruvesi: $p = 0.255$, $p < 0.01$; Table 5), suggesting that the variables may be measuring distinct conceptualizations (thresholds of hazard and consequence and direct elicitation of demand for DDR; Table 4). The same is true for the three measures of RP. The difference between the two RT variables is further supported by their variation in correlations with measures of RP across the sites. For example, comparing RT and RP in Spercheios, only RT_demand and "concern" are significantly correlated ($p = -0.399$, $p < 0.01$). This raises a question about the validity of the scale variable RT_scale (at least in this site). Contrarily, in Catterline, all RT and RP variables show significant correlations. The most striking commonality across the sites in this regard is the relatively strong significant correlations between RT_demand and "concern" (Catterline: $p = -0.458$, $p < 0.01$; Spercheios: $p = -0.399$, $p < 0.01$; Puruvesi: $p = -0.722$, $p < 0.01$). The highest RT—RP correlation at $p = -0.722$ ($p < 0.01$) in Puruvesi indicates multicollinearity, but these variables are not used together in subsequent regression models, and therefore this is not an issue (Bryman & Cramer, 1994). "Behavioral acceptance" has significant correlations with most of the RP and RT variables, supporting its testing as the dependent variable. An EFA of all RP and RT variables together does not show differentiation, with only one factor explaining 40.87% of variance in Catterline and communalities exceeding 1 in Spercheios and Puruvesi (Table S4).

3.2.2 | Explaining variation in behavioral acceptance

This section is divided into three hypotheses tested using regression models.

H1: RP and RT will be significant predictors of acceptance of NbS.

For RP, both concern and consequences are moderate to strong significant predictors of behavioral intention in all three sites (Table 6). Contrarily, perceptions of hazard frequency (RP_frequency) are only significant in one site, Puruvesi, and only weakly ($F(1,185) = 5.89$, $p < 0.05$; $R^2 = 0.031$). The RT scale is only significant in Puruvesi ($F(1,185) = 14.938$, $p < 0.01$; $R^2 = 0.075$), but RT_demand is significant across the sites and strong in Catterline ($F(1,65) = 23.457$, $p < 0.01$; $R^2 = 0.286$) and Spercheios ($F(1,82) = 9.320$, $p < 0.01$; $R^2 = 0.103$).

H2: RP and RT will iteratively explain significantly more variance in behavioral acceptance.

We test for significant changes in R^2 using the RP variable "concern" for the Catterline model and the RP variable "consequences" for Spercheios and Puruvesi (Table 7). Results using the other RP variable ("concern" or "consequences") produced similar results. We find that RT significantly adds to the predictive ability of RP in all three sites (Catterline: R^2 Change 0.118, $p < 0.01$; Spercheios: R^2 Change 0.073, $p < 0.05$; Puruvesi: R^2 Change 0.029, $p < 0.05$). This supports its merit as a separate and complementary concept for predicting behavioral intention to reduce risk.

However, taking RP and RT together, there is not much total variance in behavioral acceptance explained, at least in Spercheios and Puruvesi (15.9%, and 16.5%, respectively). This is expected given that we only capture one dimension of

TABLE 5 Correlation matrices of survey variables for each study site (A: Catterline, B: Spercheios, C: Puruvesi) as well as the mean and standard deviation (SD) per variable. The mean value is given with the maximum possible value for that variable in each site (mean/maximum possible)

(A) Catterline

Mean	SD	Variables	RT_scale	RT_demand	RP_frequency	RP_concern	RP_consequences	Behavioral acceptance
3.39/9	2.05	**RT_scale**	1.000	0.544**	−0.252*	−0.350**	−0.434**	−0.191
7.30/9	2.16	**RT_demand**		1.000	−0.375**	−0.458**	−0.436**	−0.461**
4.80/9	1.96	**RP_frequency**			1.000	0.294*	0.212	0.226
6.79/9	2.09	**RP_concern**				1.000	0.533**	0.507**
3.08/5	1.08	**RP_consequences**					1.000	0.510**
6.32/9	2.00	**Behavioral acceptance**						1.000

(B) Spercheios

Mean	SD	Variables	RT_scale	RT_demand	RP_frequency	RP_concern	RP_consequences	Behavioral acceptance
2.96/9	2.18	**RT_scale**	1.000	0.259*	−0.055	−0.207	−0.012	−0.264*
7.95/9	1.83	**RT_demand**		1.000	−0.047	−0.399**	−0.204	−0.335**
5.68/9	2.57	**RP_frequency**			1.000	0.416**	0.340**	0.185
7.49/9	1.96	**RP_concern**				1.000	0.270*	0.328**
3.53/9	1.56	**RP_consequences**					1.000	0.286**
7.09/9	1.76	**Behavioral acceptance**						1.000

(C) Puruvesi

Mean	SD	Variables	RT_scale	RT_demand	RP_frequency	RP_concern	RP_consequences	Behavioral acceptance
1.96/7	1.23	**RT_scale**	1.000	0.255**	0.010	−0.225**	−0.288**	−0.254**
6.15/7	1.61	**RT_demand**		1.000	−0.294**	−0.722**	−0.221**	−0.264**
3.93/7	1.64	**RP_frequency**			1.000	0.341**	0.231**	0.174*
5.95/7	1.51	**RP_concern**				1.000	0.284**	0.268**
3.20/6	1.20	**RP_consequences**					1.000	0.385**
4.93/7	1.30	**Behavioral acceptance**						1.000

*$p < 0.05$.
**$p < 0.01$.

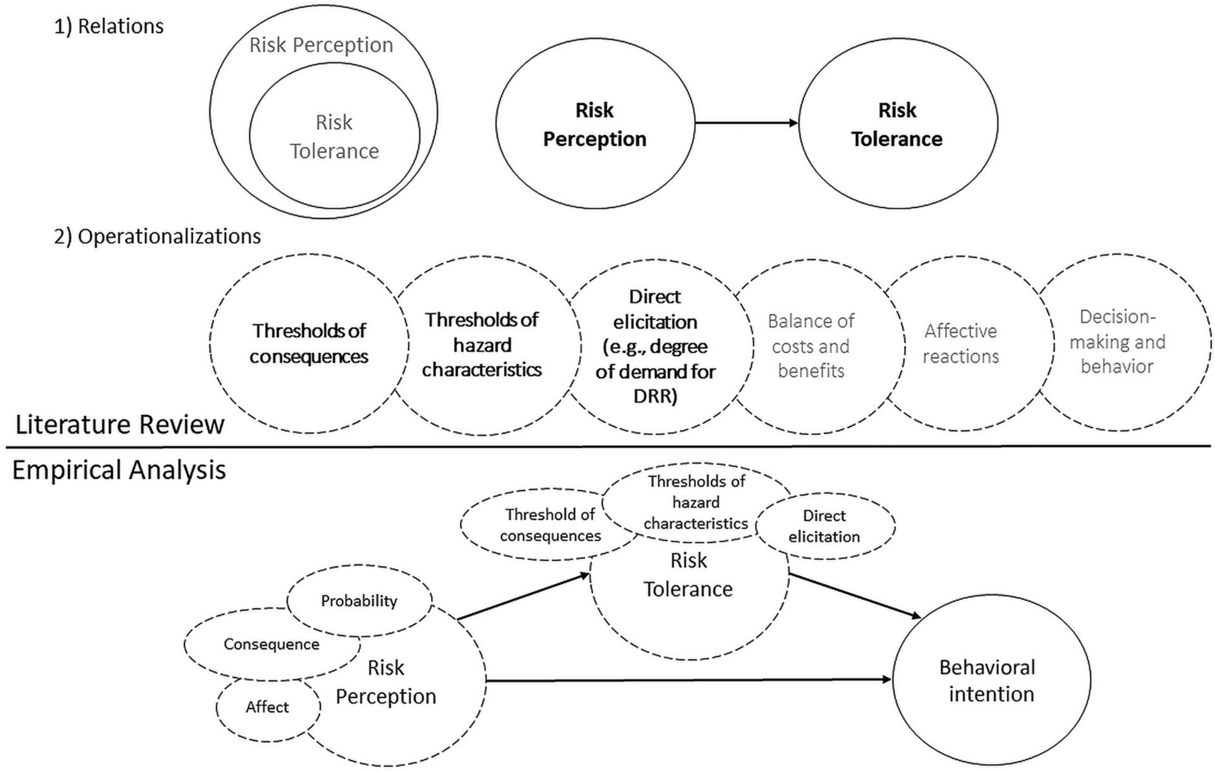

FIGURE 2 Literature review findings (top) used in the empirical analysis (bottom). Bold text shows the relation between risk perception (RP) and RT used in the subsequent empirical analysis. The mediation diagram shows what operationalizations were used for the empirical analysis (bottom). We test the relation of RP leading to RT based on several of its operationalizations from the literature review. One variable (RT_scale) uses the operationalization of "threshold of consequences" and "thresholds of hazard characteristics," and another variable (RT_demand) uses "direct elicitation."

RT and RP per variable (Wilson et al., 2019) and the complexity of behavior (behavioral intention here) with a broad range of excluded predictive factors (e.g., trust, self-efficacy, perceived effectiveness; Huang et al., 2013; Wachinger et al., 2013). The 36.4% explained in Catterline ($F(2,65) = 18.037$, $p < 0.01$; $R^2 = 0.364$)) is substantial and suggests that RP and RT together are important in determining Catterline residents' intention to actively support the NbS for DDR measures.

H3: RT will mediate the relation between RP and acceptance of NbS.

Having established in the previous hypotheses that RP and RT are separate concepts that explain significantly more variance in behavioral acceptance when taken together, we test the relationship among these concepts. As expected, RP negatively affects RT but only significantly in Catterline and Puruvesi (b = −0.428, SE = 0.103, $p = 0.001$; b = −0.271, SE = 0.62, $p = 0.000$, respectively), that is, an increase in RP significantly explains a decrease in RT. In all three sites, RT significantly negatively influences behavioral acceptance in the models (Figure 3).

Also in Catterline and Puruvesi, but not Spercheios, RT is a significant partial mediator between RP and behavioral acceptance (b = 0.150, SE = 0.062, $p < 0.05$; b = 0.051, SE = 0.028, $p < 0.05$; Table 8). This is demonstrated in the increased strength of the total model (which includes RT mediating), from a model of only considering the effect of RP on behavioral acceptance. Thus, RT acts as a mediator to strengthen the explanatory power of RP. In other words, a significant degree of the predictive ability of RP on behavioral acceptance depends on the effect of RP on RT and, subsequently, RT on behavioral acceptance.

RP acting as an antecedent to RT is supported by the underlying theory outlined in findings from the literature review. However, we ran further mediation models with the same RP and RT variables to determine whether there is also statistical evidence for *RP acting as a mediator* between RT and behavioral acceptance. We find very little difference in output in this alternate causal arrangement (Table S5). Therefore, when only considering the data, we find no support for one causal arrangement over the other.

4 | DISCUSSION

Several key findings emerge from the literature review and statistical analyses. Overall, we have shown that RT can be useful for determining behavioral intention to actively support NbS measures for DDR. Further, our results support the treatment of RT as a separate and complementary concept to RP. In the review, we found that RP is often thought to have an inverse relation with RT (e.g., Buchecker et al.,

TABLE 6 Simple regression models with all RP ($n = 3$) and RT ($n = 2$) variables for each study site: (C = Catterline, Scotland; S = Spercheios, Greece; P = Puruvesi, Finland). Highlighted in bold are the variables we use for subsequent analyses for each site for each concept since they explain the most variation in the DV. Variables not retained have a gray background. To capture RP and RT, we thus use RP_concern and RT_demand for Catterline (C), RP_consequences and RT_demand for Spercheios (S), and RP_consequences and RT_Scale for Puruvesi (P). The DV is the behavioral acceptance scale, and the IV are the RP and RT variables

DV							
Behavioral acceptance							
IV	**Site**	**df**	**b**	**SE**	**β**	**R²**	***F***
RP							
RP_frequency	C	65	0.232	0.125	0.226	0.051	3.454
RP_frequency	S	82	0.136	0.074	0.200	0.040	3.358
RP_frequency	P	185	0.140	0.058	0.176*	0.031	5.890*
RP_concern	**C**	**65**	**0.477**	**0.104**	**0.496****	**0.246**	**20.890****
RP_concern	S	82	0.247	0.094	0.281*	0.079	6.920*
RP_concern	P	185	0.204	0.063	0.231**	0.053	10.375**
RP_consequences	C	65	0.768	0.198	0.436**	0.190	14.991**
RP_consequences	**S**	**82**	**0.291**	**0.105**	**0.294****	**0.086**	**7.645****
RP_consequences	**P**	**185**	**0.349**	**0.065**	**0.368****	**0.136**	**28.911****
RT							
RT_scale	C	65	−0.199	0.120	−0.204	0.042	2.776
RT_scale	S	82	−0.128	0.092	−0.153	0.023	1.933
RT_scale	**P**	**185**	**−0.292**	**0.075**	**−0.274****	**0.075**	**14.938*****
RT_demand	**C**	**65**	**−0.480**	**0.099**	**−0.518****	**0.286**	**23.457****
RT_demand	**S**	**82**	**−0.336**	**0.110**	**−0.321****	**0.103**	**9.320****
RT_demand	P	185	−0.150	0.060	−0.181*	0.033	6.214*

*$p < 0.05$.
**$p < 0.01$.

TABLE 7 Stepwise regression models of RP and RT in Catterline (C), Spercheios (S), and Puruvesi (P). The first regression model step (1) is a repeat of the single models from Table 6. For every subsequent model (step), the change in R^2 and corresponding significance is calculated with the addition of each variable. The F change test shows whether the change in R^2 is significant

Steps	IV	b	SE	β	df1	df2	R^2	F	R^2 change	F change
C-1	RP_concern	0.477	0.104	0.496**	1	64	0.246	20.890**		
C-2	RP_concern	0.327	0.106	0.340**	2	63	0.364	18.037**	0.118	11.694**
	RT_demand	−0.350	0.102	−0.377**						
S-1	RP_consequences	0.291	0.105	0.294**	1	81	0.086	7.645**		
S-2	RP_consequences	0.238	0.104	0.241*	2	80	0.159	7.556**	0.073	6.909*
	RT_demand	−0.288	0.109	−0.275**						
P-1	RP_consequences	0.349	0.065	0.368**	1	184	0.136	28.911**		
P-2	RP_consequences	0.330	0.065	0.348	2	183	0.165	18.034**	0.029	6.320*
	RT_demand	−0.103	0.057	-0.125						

*$p < 0.05$.
**$p < 0.01$.

2013; Markanday et al., 2022) and acts as a precursor to RT (Bronfman et al., 2015; Eriksson, 2014; Huang et al., 2013). RP and RT are related mostly through a consideration of costs and benefits and their alignment to reach a "target level" of risk, which may be achieved through behavioral response (e.g., Tappenden, 2014). However, there was a lack of research assessing the RT of individuals in relation to natural hazards, both implied by the low number of articles reviewed ($n = 23$) and explicitly stated in the literature (e.g., Favereau et al., 2018).

In our empirical analysis, although RP measures of concern and consequence were generally the most predictive of behavioral acceptance, RT was also a significant predictor. Crucially, RT added significantly to the explanatory

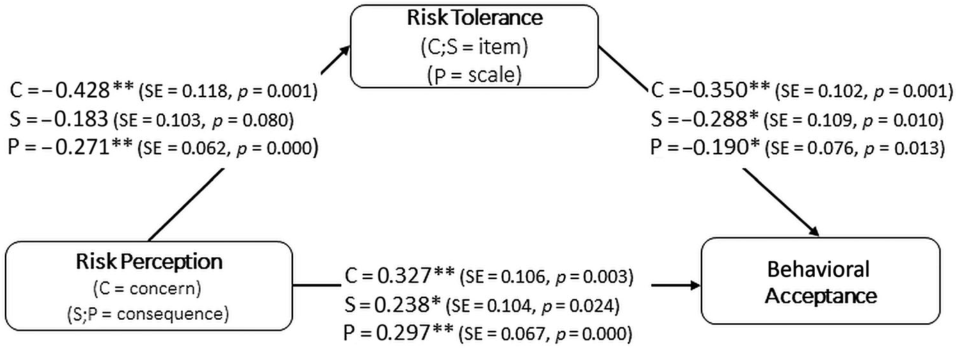

FIGURE 3 Path diagram of direct effects among RP, RT, and behavioral acceptance with RT variables mediating the relation between RP and behavioral acceptance. The β coefficients for each of the three sites (C: Catterline; S: Spercheios; P: Puruvesi) are shown, depicting the strength of the paths in the diagram. We test for mediation here only with the RP and RT variables found to be the strongest predictors from H1 (the specific variables tested for each construct are shown in the boxes in the diagram).

TABLE 8 Mediation model statistics using the PROCESS macro for SPSS with RP as the predictor, RT as the mediator, and behavioral acceptance (BA) as the outcome variable for each study site

Site	Predictor (X)	Mediator (M)	Outcome (Y)	R^2	*F*	*p*	df1	df2
Catterline (C)	RP_concern	RT_demand	BA	0.246	20.890**	0.000	1	64
Spercheios (S)	RP_consequence	RT_demand	BA	0.086	7.645**	0.007	1	81
Puruvesi (P)	RP_consequence	RT_scale	BA	0.136	28.911**	0.000	1	184
						95% c		
Site	**Effect**	**% Mediation**	**b**	***p***	**SE**	**Lower**	**Upper**	**Sobel test**
C	Indirect	31.4	0.150*[a]	–	0.062	0.035	0.278	2.91**
	Direct	68.6	0.327**	0.003	0.106	0.115	0.539	
	Total	100	0.477**	0.000	0.104	0.268	0.685	
S	Indirect	18.2	0.053[b]	–	0.049	−0.022	0.167	1.53
	Direct	81.8	0.238*	0.024	0.104	0.032	0.444	
	Total	100	0.291**	0.007	0.105	0.082	0.500	
P	Indirect	14.9	0.051*[c]	–	0.028	0.006	0.116	2.86**
	Direct	85.1	0.297**	0.000	0.067	0.165	0.430	
	Total	100	0.349**	0.007	0.065	0.221	0.477	

[a]Site C: $\beta = 0.156$*; SE = 0.065; Lower = 0.037; Upper = 0.288.
[b]Site S: $\beta = 0.053$*; SE = 0.049; Lower = −0.021; Upper = 0.167.
[c]Site P: $\beta = 0.054$*; SE = 0.030; Lower = 0.007; Upper = 0.112.
*$p < 0.05$;
**$p < 0.01$.

power of RP across all three study sites. We have also shown that RT can significantly and consistently mediate the relation between RP and behavioral intention to reduce risk. Taken together, these findings are one step toward potentially resolving the so-called "risk perception paradox" (Wachinger et al., 2013), that is, the inconsistent and often weak relation between RP and behavior. Findings from the literature review support the relation that RP can cause RT and both can cause behavior. The stepwise regression models conducted in response to H2 showed that RT significantly increases the explanatory power of RP on behavioral acceptance ($p < 0.05$). Two of the three mediation models created for H3 supported the hypothesis, suggesting that a significant proportion of the causal influence of RP on behavioral intention is dependent on RT. However, while H3 was thus largely confirmed by the data, mediation models with instead RP mediating the relation between RT and behavioral acceptance showed a very similar output. Therefore, the data did not provide evidence to support the hypothesized causal arrangement over this alternative. Given the scarcity of highly relevant articles found in the literature review, future research should further scrutinize the assumed causal configuration of the concepts. With larger datasets, assessing model fit using structural equation modeling, for example, could help build a more reliable theoretical underpinning.

Our study does not allow us to determine why the Spercheios study site diverged regarding the significance of the mediation models tested in H3. However, this could be due to many factors, including cultural differences, hazard type and proposed NbS, and so forth (Table 2; Anderson &

Renaud, 2021). In Spercheios, the wider basin area was considered the study area, and therefore respondents were from the larger city of Lamia and surrounding villages. Contrarily, residents surrounding Lake Puruvesi in Finland are more homogenous, as well as respondents from the small and tight-knit community of Catterline. We urge caution in interpreting cultural differences between respondents given the lack of methodological consistency across sites. However, further descriptions of the study areas, respondents, and potential influencing factors behind survey response discrepancies can be found in Anderson et al. (2021).

The most direct recommendation stemming from our work is that RT should be more consistently considered within research on RP. For example, on surveys that assess RP, additional items that explicitly operationalize RT should complement traditional RP items. Our RT scale based on thresholds of hazard and consequence performed reasonably well but requires external validation and testing in different contexts. Moreover, although correlations show that our RP and RT variables were sufficiently distinct, a factor analysis did not further support differentiation and clear measuring of distinct underlying constructs. Using larger samples with factor analysis and including a range of items aimed at capturing RT as a multi-dimensional and latent construct would contribute to the theoretical discussion and support standardized scale development. Ultimately, this could increase the comparability, validity, and replicability of future work. There is a need to create and test scales that go beyond "demand for DDR" to represent the different operationalizations of RT found in our literature review: RT in relation to consequence, cost-benefit, behavior, or hazard characteristics. A more specific weakness of our RT scale is the difficulty in defining frequency thresholds for the items related to hazard frequency and consequence (i.e., every 5 years, 10 years, etc.). Results were mostly skewed toward low RT, similar to Slovic et al. (1985), so future measures should strive for ensuring a broader range of responses and ideally use actual behavior rather than only intention.

Understanding RT, like RP, has important implications for risk communication. In particular, understanding what may be perceived as risky but is nevertheless tolerable can help align risk managers and public expectations of hazard response. In the case of NbS, this is particularly important since such DDR measures are not as immediately effective due to a time lag for vegetation to stabilize (Kabisch et al., 2016; Shah et al., 2020). Understanding whether exposed individuals will tolerate certain thresholds of risk in the meantime could be useful information for policy makers and planners. Additionally, the benefits of living with a hazard are more directly related to NbS as a risk mitigation option than other methods. For example, the public's willingness to allow room for rivers to flood is a crucial component of increasingly popular river and floodplain restoration projects (Buijs, 2009; Holstead et al., 2017). Understanding stakeholders' tolerance to the risk of minor impacts versus major impacts could help identify potential divergence in DDR project expectations and help avoid or resolve related conflicts.

We view our study as a first step that lays the groundwork for much-needed further research on this topic. First, as mentioned, further developing methods to assess RT is important. Here, inspiration can be drawn from research on domain-specific risk and risk aversion and the DOSPERT scale (Weber et al., 2002). Such research could also be used to support studies on how the perceived benefits associated with natural hazard risk and risk-taking behavior relate to benefits of risks that typically involve clear gains (e.g., financial). Second, research is needed in different social-ecological contexts, including in developing countries. Our review showed that RT is considered more relevant when the benefits derived from RT are greater (Tappenden, 2014; Vinnell et al., 2016). Thus, risk situations with potential benefits to life and livelihood could help further develop the concept. In this study, no death has been recorded as a potential consequence of the respective hazards in the last several decades. Also, the public expectation of protection is relevant (Nathan, 2008), and the degree to which risk reduction actions provide personal or societal benefits can influence individual decision making (Geaves & Penning-Rowsell, 2015) should be explored in the context of RT. As proposed in the RP-MAM by Anderson et al. (2021), considering the co-benefits of measures, including ecosystem services (as well as disservices) could prove useful for investigating *benefits and costs* in relation to RT. Further, exploring perceptions not just of hazard risk but also the risk of failure of the measure/possible response options themselves may allow for further inclusion of RT in relevant research. Research on uncertainty could also be applied in this context, for example, "outcome uncertainty" (Moure et al., 2023). Research on NbS consistently shows that there is public uncertainty and skepticism toward the effectiveness of such measures. Considering the benefits and trade-offs of NbS, using the frame of RT could support the exploration of preferences for different measure types, including those that may be greener (such as NbS), compared to more traditional gray DDR measures (Anderson et al., 2022).

Last, determining the role of RT in relation to factors within prominent behavioral theories that emerged in the literature review should be explored. Particularly relevant are risk homeostasis theory (Wilde, 1982), theory of planned behavior (Ajzen, 1991), and PMT (Rogers, 1975). Response- and self-efficacy as determinants of coping appraisal, for example, can help explain the RP-response gap (Bubeck, Botzen, & Aerts, 2012) and should be considered in relation to RT. Already in Fischhoff et al. (1978), one goal of the authors was to test the factors found to be influential in past work, including voluntariness, immediacy, "known to science," controllability, newness, chronic, common, and severity of consequences. Although these factors and others from RT literature are similar to those used within the psychometric RP paradigm to differentiate hazards, there are some nuanced distinctions. Namely, the perceived voluntariness, controllability, benefits, and trust in authorities are emphasized as especially crucial to RT (Bronfman et al., 2015; Finlay & Fell, 1997; Fischhoff et al., 1978; Gough, 1990; Mitsushita et al., 2023), and their influence should be further investigated. Additionally, the role of cognitive evaluation of benefits versus costs identified in RT literature, rather than affect, may mean that the latter is less important for RT than its established relevance to RP. It seems logical that RP may involve a quicker (and often subconscious) response in individuals, while the more calculating "system 2" of dual-process theory (Aerts et al., 2018; Altarawneh et al., 2018) may play a more exclusive role for RT. As explained by Lindell and Perry (2000), "the correlation between perceived risk and action is greatest in a warning environment where the time between the activation of the risk assessment and the need for reaction is shorter."

5 | CONCLUSION

The concept of RT is well established in other research fields such as economics and public safety in which the costs and benefits of risk are often more salient. Foundational RP research, particularly within the psychometric paradigm, was concerned with the question "How safe is safe enough" (Starr, 1969). Since then, the field of natural hazards and risk reduction has primarily treated this question as a technical matter at the societal level, usually graphed in relation to probability of mortality or infrastructure failure. We have shown using a literature review that the concept has not been sufficiently taken up from the perspective of individuals' perceptions in relation to demand for risk mitigation and behavioral response. Our analysis of empirical data suggests that the concept of RT deserves systematic consideration alongside other factors for explaining behavior in response to natural hazards. In particular, it can be useful as a complementary concept within RP studies and a step toward resolving the "risk perception paradox." For reducing risk from natural hazards, active public engagement is increasingly required and is central to the success of NbS. Understanding individuals' perceptions and responses, including levels of RT and the factors behind these, will be crucial for effective risk communication, planning, and policy.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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