Kleespies *et al.*
Environmental Sciences Europe (2024) 36:122
https://doi.org/10.1186/s12302-024-00950-5

Environmental Sciences Europe

RESEARCH

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Assessing the unseen consequences: influence of an extreme weather event on environmental perceptions and connection to nature

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Abstract

Background Due to climate change, extreme weather events are becoming more frequent worldwide. An example of such an extreme weather event was the flooding in Western Europe in July 2021. Currently, there are large research gaps regarding how such events, particularly those involving oil pollution, affect people's connection to nature and their perceptions of environmental problems. Perceptions and connections to nature are important factors that influence environmental behavior and decisions. This study examines the influence of the exposure of oil pollution during the 2021 floods on the perception of the natural environment (connection to nature) and of environmental problems (perception of planetary boundaries). To this end, people affected by flooding who have come into direct or indirect contact with oil pollution are examined, with people from unaffected regions serving as a control group.

Results No significant differences were found for both the connection to nature and the perception of planetary boundaries between the three groups studied. Connection to nature was at a moderate level in all three groups. In the case of planetary boundaries, it was observed that all boundaries were rated as significantly exceeded in all three groups. Especially the boundary of novel entities to which also oil pollution belongs, was evaluated as highly exceeded.

Conclusions The results suggest that extreme weather events do not negatively impact personal connection to nature. Additionally, no significant group differences were found in the assessment of planetary boundaries, which may be attributed to the inherently high assessment scores in Germany. The study provides evidence that perceptions of environmental problems and connection to nature are relatively stable in the face of an extreme weather event with a natural trigger. Further studies are needed to investigate the reasons and consequences of this stability.

Keywords Connection to nature, Survey, Planetary boundaries, Novel entities, Oil pollution, Extreme weather event, Flood, 2021 flooding

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Background

Recent studies indicate that the duration, frequency and intensity of extreme weather events will increase in the future [1, 2]. The term 'extreme weather event' generally refers to weather conditions that occur only very infrequently [3], such as heatwaves, extremely cold temperatures and massive storms that often result in subsequent flooding [4]. Climate change, in particular, is contributing to the rising likelihood of such extreme weather events also in Europe [5]. Floods rank among the most frequent extreme weather events and have been responsible for many deaths in recent decades [6]. Moreover, these events have negative effects not only on physical health, but also on mental health [7].

In July 2021, Western Europe, including Germany, Belgium, the Netherlands, France and Luxembourg, experienced a severe flood disaster. In Germany, over 180 people lost their lives and more than 800 were injured, some of them severely [8]. Caused by heavy rain, this flood is regarded as one of the most devastating natural disasters in Germany in the last hundred years, with estimated economic damages exceeding 30 billion euros [9].

In addition to the visible impacts, such flood events often result in the (re)mobilization of pollutants, including those from damaged oil tanks or historical discharges [10], even though flood-related chemical pollution often does not receive much attention in the media [11]. As petroleum is still an important source of energy worldwide, pollution and contamination from oil occurs regularly [12]. The negative effects on human health [13] and ecosystems are well documented for oil pollution [14]. Nevertheless, there is still an urgent need for research in the field of chemical pollution [15]. As the consequences of oil spills can sometimes last for years, they are of particular importance [16].

The effects of different extreme weather events or their consequences on attitudes towards environmental problems have been investigated in various research contexts. For example, there are studies which have examined the effects of tsunamis [17], general environmental pollution [18], earthquakes, landslides [19], tornadoes, hurricanes [20], wildfires [21] and severe cold spells [22] on people's perceptions of environmental problems. However, there is a research gap when it comes to the relationship between oil spills during an extreme weather event and different environmental attitudes. The situation is similar when it comes to connection to nature. There are a few studies that examine the connection to nature after an extreme weather event [23, 24], but not in combination with an oil spill after a flood.

As connection to nature and perceptions are important indicators for environmental behavior and decisions [25–27], researching these can be of particular importance in the context of extreme weather events.

Human–nature relationships: connection to nature

An individual's connection to nature is considered an important factor that can influence their environmental behavior positively [28–31]. Additionally, there is evidence that connection to nature can have a positive impact on personal health, leading to increased well-being, reduced stress, improved immune function and increased happiness [32–34]. Given the numerous positive effects associated with an increased personal connection to nature, it would be beneficial to examine the impact of an extreme weather event on this relationship. It could be hypothesized that such events disrupt individuals' personal relationships with nature, potentially leading to a decline in connection to nature. This decline might have a negative impact on environmental behavior and personal health, highlighting the importance of studying how extreme weather events affect human–nature relationships.

Due to the significance of the human–nature relationship, there has been a substantial increase in publications across various disciplines over the past two decades [35]. The concept of the human–nature relationship or connection to nature is particularly often explored in environmental psychology. However, there is no universally accepted definition and different authors emphasize various aspects of the human–nature relationship. Depending on the concept, connection to nature is seen as the personal interconnectedness with all other living things on the earth [28], as part of one's identity [36], the perception of equality between oneself and the natural world [37] or as the emotional connection to nature [29]. The concept of Inclusion of Nature in Self (INS) by Schultz [38] is particularly common. In this concept, connection to nature consists of three dimensions: connectedness, caring and commitment to protect nature. Due to the widespread use of this concept, the repeatedly proven validity [39, 40] and the simple applicability of the associated measurement instrument [41], the INS was used as the underlying concept of connection to nature in this study.

In addition to the connection to nature, the perception of environmental problems also plays an important role. Attitudes and concerns about environmental problems can directly impact how people interact with nature [42].

Perception of environmental problems: the boundaries of our planet

The Earth System is currently facing major environmental problems that can have far-reaching negative consequences [43]. In 2009, the framework of "planetary

boundaries" was introduced to define a safe operating space for nine Earth System processes within which humanity can safely operate. Crossing a critical threshold (boundary) can result in irreversible damage to the Earth System, potentially causing devastating consequences for both humans and the environment [44, 45]. These boundaries are interrelated and can strongly influence each other [46]. The concept is regularly updated and previously unquantified boundaries, like novel entities, are now included [45, 47]. Novel entities are new substances that would not be present in the Earth system without human intervention [47] and show undesirable geophysical and/or biological effects [45]. Oil pollution can be considered a form of novel entity, as oil or oil products are only introduced into the environment due to human activity and can have negative effects in various ways.

The perception of environmental problems has been repeatedly identified in the literature as a factor that has an influence on personal environmental behavior and thus on sustainability. For example, an increased perception of risk leads to more sustainable consumer behavior [48]. People are more willing to save energy if they perceive climate change as an increased threat. [49]. Risk perception can also increase concern for the environment, which can lead to more sustainable behavior [50]. Increased risk perception due to an extreme weather event could therefore be a possible factor for greater sustainability. Previous studies have already provided evidence that people's environmental actions can increase in the period after an extreme weather event [24].

These risk perceptions of environmental problems, as described in the planetary boundaries, can be influenced by extreme weather events. For example, it was found that people who suffered direct financial damage or indirect damage due to interference with their personal lives as a result of an extreme weather event such as a landslide or flooding consider these events to be more threatening in the future than people who have not had such an experience [19].

Tornadoes or wildfires can also increase the perception of environmental problems if they harm a person or their community. In particular, economic damage or the negative impact on public well-being are factors that have a strong influence [21]. Experiencing a local flood can amplify concern about environmental issues, decrease uncertainty regarding their impact and make people more likely to take action to mitigate these problems [51]. Particularly when extreme weather events are perceived as a consequence of an environmental problem, such as climate change, and there is a personal impact and large casualties concern for those environmental problems rises [52]. Other studies reported small but noteworthy increases in concern for environmental issues following extreme weather events [53]. Emotions surrounding environmental problems can also be influenced by extreme weather events [54]. Some studies have even found that concern about environmental problems can increase, even when extreme weather events occur in other countries [55, 56]. It is worth noting that these events seem to have the most impact when they have occurred recently [53].

Particularly due to the heavy oil exposure in some parts of Germany after the 2021 flood catastrophe, is it possible that individuals who were in direct contact with oil spills would be more likely to perceive the novel entities (which include oil pollution) as being exceeded.

This study aims to examine whether the extreme weather event in Europe in 2021 affected (a) people's connection to nature and (b) their perception of environmental problems. For this purpose, a survey was conducted in Stolberg (North Rhine-Westphalia, Germany), a city particularly affected by the flood. The results from Stolberg were compared with a control group from another city in Germany that was not affected by the flood.

Additionally, given that people in Stolberg were significantly exposed to oil pollution, the study also investigates whether direct exposure to oil pollution has a special impact on the connection to nature or the evaluation of the planetary boundaries.

Methods

A quantitative survey was conducted to investigate the potential influence of direct or indirect contact with oil pollution in the flooded area on the perception of planetary boundaries, especially the boundary 'novel entities' and the personal connection to nature. Due to the voluntariness of participation, the sample used in this study was not representative, as the participants themselves decided whether they wanted to participate or not.

The study involved three groups:

(1) Individuals directly affected by oil pollution in Stolberg: this refers to study participants who stated that they were personally affected by exposure to pollutants and specified these pollutants as oil or fuel.
(2) Individuals with indirect contact to oil pollution in Stolberg: this includes study participants who live in Stolberg and were affected by the extreme weather event but reported that they were not personally affected by pollutants.
(3) A control group located outside the flood area in Frankfurt (Hesse, Germany).

Data collection procedure and study site

To reach people affected by the flooding and oil pollution following the extreme weather event in 2021, a survey was carried out in the town of Stolberg. Stolberg is a medium-sized town with around 56,000 inhabitants in North Rhine-Westphalia near the city of Aachen (Germany) [57]. Benefiting from natural resources, Stolberg has a long history in the metalworking industry and is now known as 'copper town and oldest brass town in the world' [58]. Due to its long industrial history, the town still has problems with contaminated sites today [59]. Stolberg was chosen as the study location because it was affected severely by the flood disaster in 2021, which caused major destruction and (oil) pollution [60, 61].

The survey was conducted using an online questionnaire with the EvaSys survey software. The sampling procedure was chosen for organizational reasons. The questionnaires could be easily distributed digitally among the people on site. In addition, this type of survey was in line with the requirements of the ethics committee and local regulations. A brief introduction to the questionnaire provided insight into the study's objectives, data protection and the length of the questionnaire. In the first section of the survey, the participants' socio-demographic data were collected. This included age, gender and highest level of education. The participants in Stolberg were also asked whether they had suffered personal financial damage as a result of the flood event and whether they had been personally affected by pollutants. If these questions were answered affirmatively, a text field opened asking about the amount of damage in euro or the type of pollution. In the second section, the participants' connection to nature was recorded and in the third section the perception of planetary boundaries. The entire questionnaire can be found in the supplementary information.

The city of Stolberg advertised the survey by displaying flyers about the study at the flood victim help points. These contained a brief explanation of the study and a QR code that led to the online questionnaire. In addition, the survey was distributed by a representative of the city via social media channels with the call to support this study. This resulted in a sample size of 103 respondents from the flood area. Of these, 29 people stated in the questionnaire that they had come into direct contact with oil or fuel.

To minimize bias during data collection, several measures were implemented. Firstly, the survey distribution in Stolberg involved multiple channels, including displaying flyers at flood victim help points and distributing the survey link through social media. In addition, the objectives of the survey were explicitly stated and the participants were assured of data protection, so that it can be assumed that the questions were answered honestly. However, as the survey was only possible on a voluntary basis and online due to local circumstances, a certain bias cannot be ruled out.

The survey of the control group was conducted by a marketing research institute based in Germany. An email distribution list of people living in Frankfurt and its surrounding areas was used for distribution of the questionnaire. The chosen mailing list, usually used for market research, included a diverse range of people of different ages and educational backgrounds. A total of 3500 people were messaged, 192 of whom completed the questionnaire (approx. 5.5%).

Only persons of legal age were surveyed and the data collection took place in May and June 2022.

Measurement perceptions of planetary boundaries

The questionnaire presented a list of the eight quantified planetary boundaries, including novel entities, ocean acidification, altered phosphorus and nitrogen flows, atmospheric aerosol loading, freshwater use, land-system change, stratospheric ozone depletion, climate change and loss of biosphere integrity to assess how the three different groups perceive the planetary boundaries. Respondents were asked to rate whether they thought these limits had been exceeded on a six-point unipolar scale ranging from "not exceeded" to "greatly exceeded". For clarity, the questionnaire provided explanations and examples for some boundaries. For the group surveyed in the flood-affected area, the questionnaire also captured whether respondents had direct contact with oil, gasoline or diesel pollution due to extreme weather events.

Measurement connection to nature

The Inclusion of Nature in Self Scale (INS), developed by Schultz [38], was used to measure an individual's personal relationship with nature. This graphical measure comprises seven overlapping pairs of circles. One circle is labeled "me", while the other is labeled "nature". The degree of overlap between these circles varies, indicating the extent of one's connection to nature, ranging from no connection (completely separate circles) to one with nature (two congruent circles). Participants were instructed to select the pair of circles that best represented their personal relationship with nature. Several studies found strong positive correlations between the INS and other measurement instruments for connection to nature, affirming the scale's validity [39, 40].

Data analysis

The statistical analysis was performed using IBM SPSS 28.

Kruskal–Wallis tests were conducted to determine whether the three test groups differed in their demographic data. This test type was selected because the study variables were ordinally scaled, the data were independent and the Kolmogorov–Smirnov test could not determine a normal distribution ($p < 0.001$).

A Kruskal–Wallis test was also used to examine the differences in the perception of planetary boundaries and connection to nature between the three study groups, as ordinal-scaled data were examined, 3 groups were compared with each other, the data were independent and the Kolmogorov–Smirnov test could not determine a normal distribution in this case as well ($p < 0.001$).

Results

Socio-demographic characteristics

Socio-demographic data for the three groups surveyed can be found in Table 1.

The results of the Kruskal–Wallis tests showed that there was no significant difference between the three groups for age ($H(2) = 5.665$, $p > 0.05$), gender ($H(2) = 2.255$, $p > 0.1$) and education level ($H(2) = 4.680$, $p > 0.05$).

The comparison of the socio-demographic data between the three groups surveyed showed no significant difference. It can therefore be assumed that the groups are similar in terms of age, gender and level of education.

However, the distribution differs significantly from the German resident population over the age of 18, meaning that this is not a representative survey. In particular, the higher percentage of women among the respondents, with more than 60% in all groups, is significantly higher than the German figure of 50.7% in 2022 [62]. The phenomenon that women are more likely to participate in social-scientific surveys is well known [63]. In this study the larger number of female participants could be due to the fact that women are generally more concerned about environmental problems, show more pro-environmental views [64] and are more likely to support environmental measures [65]. It is therefore likely that women, who are more interested in environmental issues were more likely to complete the questionnaire.

The age distribution in the three groups also differs from the German population: the 60 + age group is the largest in the current German population [66], but is underrepresented in the data set collected here. The survey in the control group was conducted digitally using an e-mail distribution list. It is therefore possible that on average more younger people were contacted. The survey in Stolberg was also conducted using digital questionnaires. The questionnaires were distributed there using a QR code at the victim help points and via social media. This could also have led more younger people to complete the questionnaire.

Table 1 Socio-demographic data collected for the three groups

	Group in flood area directly affected by oil pollution	Group in the flood area indirectly affected by oil pollution	Control group
Age			
18–29	5 (20.0%)	13 (20.6%)	16 (10.7%)
30–44	9 (36.0%)	23 (36.5%)	47 (31.5%)
45–59	9 (36.0%)	19 (30.2%)	60 (40.3%)
60 +	2 (8.0%)	8 (12.7%)	26 (17.4%)
No indication	4	11	43
Gender			
Male	10 (35.7%)	26 (35.1%)	50 (26.2%)
Female	18 (64.3%)	47 (63.5%)	141 (73.8%)
Diverse	0 (0.0%)	0 (0.0%)	0 (0.0%)
No indication	1	1	1
Level of education			
No/lower secondary school (up to 9 years school)	0 (0.0%)	9 (12.2%)	5 (2.6%)
Secondary school (10 years school)	11 (39.3%)	20 (27.0%)	57 (30.0%)
High school (12–13 years school)	6 (21.4%)	22 (29.7%)	42 (22.1%)
Academic degree	11 (39.3%)	23 (31.1%)	86 (45.3%)
No indication	1	0	2

The percentages in brackets refer to the valid responses, excluding people who did not provide any information in this category

In the sample, the number of people with a higher level of formal education was also above the population average. Education is also considered an important factor when it comes to concern about environmental problems [67] or pro-environmental behavior [68]. This more positive attitude towards environmental issues could have contributed to the fact that this group completed the questionnaire more frequently.

It is important to note in this context that education, age and gender can be seen as possible influencing factors on the perception of environmental problems and connection to nature [69–71]. These characteristics could also have had a possible effect in this sample. However, as there was no significant difference between the three study groups in terms of age, gender and level of education, it can be assumed that the groups remain comparable, even if they differ in their composition from the German population. However, for this reason it should be noted that the results are not generalizable for the entire population in Germany.

Group comparison of perceptions of environmental problems and connection to nature

The Kruskal–Wallis test revealed no significant differences among the three groups in their evaluations of the eighth planetary boundary (Table 2). Whether individuals in the flood-affected area were directly or indirectly impacted by oil pollution or were members of the control group had no significant effect on the assessment of the planetary boundaries.

Overall, all three groups assessed all boundaries as significantly exceeded, placing them within the zone of uncertainty (Fig. 1). Notably, even those boundaries that show no overshoot, such as freshwater use, ocean acidification and stratospheric ozone depletion, were perceived as severely exceeded by respondents across all groups.

Table 2 Means and standard deviation of the assessment of planetary boundaries for the three groups

Planetary boundary	Group			
	Group in flood area directly affected by oil pollution	Group in the flood area indirectly affected by oil pollution	Control group	*p*-value of the Kruskal–Wallis test between the three groups
Novel entities	4.44 ± 1.16	4.35 ± 1.06	4.33 ± 1.07	$p = 0.821$
Ocean acidification	3.44 ± 1.34	3.41 ± 1.34	3.69 ± 1.32	$p = 0.156$
Altered N & P flows	3.52 ± 1.53	3.80 ± 1.24	3.74 ± 1.22	$p = 0.604$
Freshwater use	3.22 ± 1.70	3.25 ± 1.37	3.53 ± 1.41	$p = 0.179$
Land system change	3.19 ± 1.59	3.25 ± 1.56	3.54 ± 1.44	$p = 0.131$
Stratospheric ozone depletion	3.52 ± 1.42	3.23 ± 1.42	3.63 ± 1.34	$p = 0.097$
Climate change	3.93 ± 1.17	3.83 ± 1.37	4.10 ± 1.28	$p = 0.106$
Loss of biosphere integrity	3.93 ± 1.36	4.06 ± 0.97	4.02 ± 1.25	$p = 0.756$

The ratings could take values between 0 and 5, with 5 representing a high overshoot

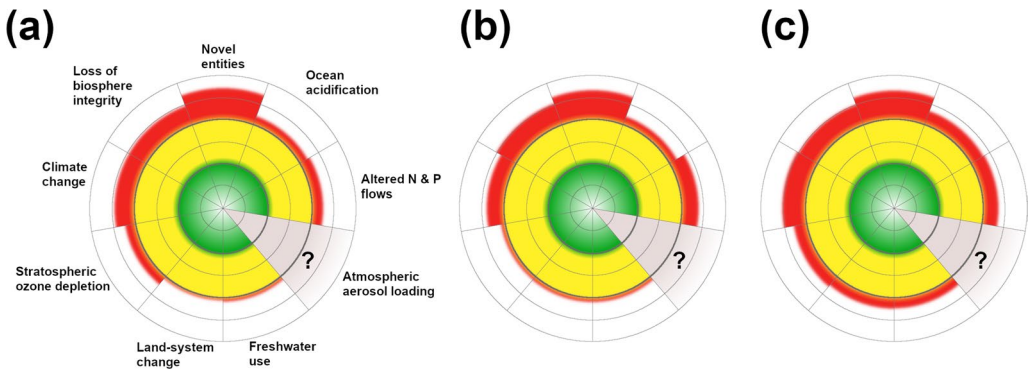

Fig. 1 Results of the assessment of the exceeding of the planetary boundaries in the three groups. Each of the rings within a circle represents the rating on the rating scale, from the innermost circle (not exceeded) to the outermost circle (greatly exceeded). The coloring corresponds to the illustration by Steffen et al. [45] and in this case highlights how far the boundary has already been assessed as exceeded (red indicates very strongly exceeded, green not/barely exceeded). **a** Persons in the flood area directly affected by oil pollution. **b** Persons in the flood area not directly affected by oil pollution. **c** Control group

Among these boundaries, novel entities were consistently perceived as most exceeded.

For connection to nature, the Kruskal–Wallis test did not find a significant difference between the three groups ($p = 0.154$; Fig. 2). For the group in the flood area directly affected by oil pollution, the connection to nature score averaged 4.93 (± 1.303). In the group within the flood-affected area not directly impacted by the oil pollution, the score averaged 4.45 (± 1.425) and for the control group the connection to nature score was 4.74 (± 1.264).

Discussion

Connection to nature and extreme weather events

In the present study, no significant difference could be found in connection to nature between the three study groups. This implies that the extreme flooding event in Stolberg had neither a positive nor a negative impact on the connection to nature, regardless of whether people were in direct contact with oil pollution or not. The results of this study therefore differ from previous studies that have investigated the effects of an extreme weather event on the connection to nature. One study using the same connection to nature measurement instrument as this study discovered that being affected by a hurricane led to a slight increase in connection to nature, while a subsequent oil spill led to a decrease in connection to nature [24]. Another study found a negative effect of an extreme weather event on the human–nature relationship [23]. To understand why there was no change in connection to nature in our study, it is necessary to consider the factors that can influence connection to nature.

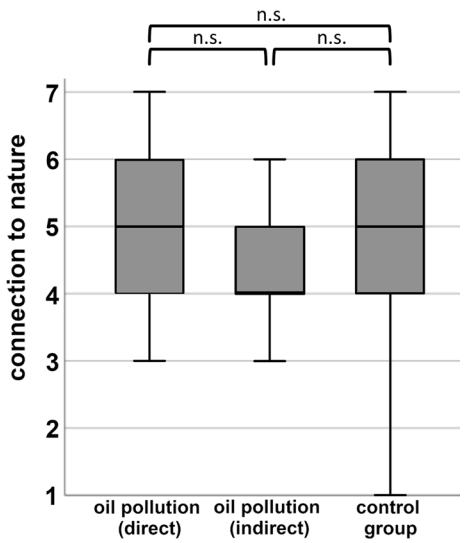

Fig. 2 Boxplots of the connection to nature scores between the three test groups. The Kruskal–Wallis test could not detect a significant difference between the three groups. (*n.s.* not significant.)

An increase in connection to nature is often linked to time spent in nature, childhood experiences and environmental education [72–74]. None of these positive main influencing factors were affected by the extreme weather event. Although it is possible, for example, that more environmental education takes place in the long term due to the extreme weather event or that people spend less time in nature due to recent damage. However, these would be effects that can only be measured long after the extreme weather event and not shortly afterwards.

A decline in the connection to nature was also not found in this study. The literature names a number of factors that can reduce the connection to nature for example time spent with electronic devices [75, 76] or the increasing loss of opportunities to connect with nature [77]. Although it is possible that there was less time and opportunities for people to spend time in nature in the short term after the extreme weather event, this effect does not appear to be large or long-lasting enough to have a negative impact on people's connection to nature. Some studies suggest that negative emotional experiences in nature may affect this connection, even if the effect is comparatively small [78–80]. There is also the assumption that negative experiences, such as disgust may negatively affect connection to nature [81, 82]. Although it can be assumed that the extreme weather event and the oil spill triggered strong negative feelings and disgust, there is no evidence that the people affected also associated these feelings with nature. Disaster literature also shows that disasters are increasingly perceived as being caused by humans, regardless of whether they are of natural or technical origin [83]. The question of what exactly happened often becomes less important; instead, responsibility and the failure to take precautions are discussed [84, 85]. This trend can also be observed during the 2021 flood disaster. In Germany, for example, poor emergency management was often heavily criticized in retrospect. The discussion often centered on the lack of alarms and early warning system and the fact that the evacuations did not work as expected [86]. In public perception, questions of responsibility and prevention were particularly prevalent after the 2021 flood. People affected by the flood stated that a lack of information and coordination were seen as the primary problems [87]. It is possible that people did not consider nature to be the trigger for this environmental disaster but rather a consequence of human-induced environmental changes [1, 88]. For these reasons, it is likely that nature was not blamed for the flooding and therefore the connection to nature was not negatively affected. When interpreting the results, however, it should also be noted that the survey took place

almost a year after the actual flood. Therefore, the data do not allow any statement to be made about a possible short-term effect on connection to nature that occurred directly after the extreme weather event and may have faded by the time the data were recorded.

In order to explain why there is no significant difference in connection to nature between the groups, further empirical and especially qualitative investigations are necessary. Especially when it comes to how perceptions of for example climate change have changed as a result of an extreme weather event, interview studies would be particularly beneficial.

Perception of environmental problems and an extreme weather event

Particularly due to the heavy oil exposure after the flood catastrophe in Stolberg, the intuitive assumption would have been that individuals who were in direct contact with oil spills would be more likely to perceive the novel entities (which include oil pollution) as being exceeded. However, the results of the current study indicate that there is no significant difference in the perception of the planetary boundaries across the three study groups. This implies that the extreme weather event and the oil spill had no significant impact on the perception of planetary boundaries.

In addition to studies that indicate an influence of extreme weather events on the perception of environmental problems [23, 24], there are also studies that are consistent with this result: an interview study in England found no difference in perceptions of climate change between flood victims and unaffected residents [89]. A meta-study revealed that experiencing extreme weather had only a very small effect on environmental concerns [90]. Wang et al. [91] even found evidence suggesting that experiencing an extreme weather event might decrease concern about environmental problems.

A possible explanation for our result is that people in the flood area may have perceived the high chemical contamination as a local issue rather than a global boundary being exceeded. Furthermore, it should also be noted that the planetary boundaries were already estimated to be significantly exceeded in all three groups particularly in the case of the novel entities. As with connection to nature, it must also be noted here that the data do not allow any statements to be made about effects directly after the extreme weather event, as the data were recorded almost a year after the event.

These findings are consistent with previous studies, which identified that in Germany, all planetary boundaries were assessed as highly exceeded. In other industrialized countries, people also assume that the planetary boundaries have been exceeded, but to a much lesser extent than in Germany [92]. Awareness in Germany for environmental problems has continued to rise in recent years, many Germans see the environment and climate as an important issue and are in favor of a climate-friendly restructuring of the economy [69]. Students in Germany in particular rate environmental problems as the most important problems currently faced by society [93]. Therefore, there may be a ceiling effect: even if the extreme weather event had an effect, it may be difficult to increase the already very high concern baseline values.

In addition to the explanations mentioned above, however, other theories and hypotheses are imaginable that could explain the similarity of connection to nature and the perception of environmental problems between the three groups. For example, coping mechanisms may have developed within the year following the extreme weather event. It is documented that people tend to develop coping mechanisms to deal with the aftermath of extreme weather events. Various studies have demonstrated the development of spirituality as a coping mechanism in such contexts [23, 94]. It is therefore possible that the people affected by the event have already processed the experience using different coping mechanisms, with the result that no significant differences were found in comparison to the control group.

It is also possible that the inhabitants of Stolberg have developed a higher tolerance to environmental and oil pollution. The town has been an industrial center for centuries, and its industrial past has left it with chemical contamination [58, 59]. As a result, the people of Stolberg may have already built up a higher tolerance to pollution before the extreme weather event, so that the additional event had less of an impact on their perceptions.

In addition, the relationship with nature and the perception of environmental problems may have been influenced by interpersonal relationships. More recent theories suggest that it is not only one's own relationship with nature that has an influence on how nature is treated and perceived, but also relationships between people that involve nature [95]. Dynamics emerging after the extreme weather event may have led to a possible effect in the community that mitigated potential negative effects of the event in the longer term. In order to determine which of these effects had an influence or whether there are other reasons, further (quantitative) investigations would be useful.

Limitations

Some limitations should be considered when interpreting the results of this study.

Due to the unpredictability of extreme weather events, it was not possible to conduct a before-and-after survey. Therefore, this study cannot draw any conclusions about

the change of the connection to nature and the perception of planetary boundaries over time.

As the survey was voluntary, it is likely that primarily people who are interested in the topic completed the questionnaire. In addition, both in Stolberg and in the control group, the data were collected using online questionnaires. It is therefore possible that younger and technology-oriented people took part in the survey. In Stolberg, the questionnaire was also distributed via social media, which may have targeted a younger audience.

Another limitation is the sample size. Efforts were made to survey as many people as possible in Stolberg. However, the group with direct exposure to oil pollution was relatively small (n = 29). Therefore, the results presented here should be considered a potential foundation for future studies involving larger survey groups to gather additional evidence regarding the impact of extreme weather events on environmental perceptions. In particular, qualitative data should be collected in order to find explanations for the results.

Some of the quantitative measurement instruments used showed a ceiling effect. This means that a portion of respondents reached the highest possible score on certain survey items. In the future, it would therefore be desirable to use other research methods, such as open-end questions or interviews, to determine the reasons for the ceiling effect and to investigate these results in more detail.

When creating the questionnaire, explanations and examples were added to the planetary boundaries to make them as easy as possible for respondents to understand. However, it is possible that these explanations may not have been sufficient for participants without a background in environmental science or related fields. Given the complexity of the concept of planetary boundaries, particularly for a non-expert audience, it is important to recognize that participants' responses may have been influenced by their level of understanding.

Conclusion

Due to ongoing environmental changes, global and regional extreme weather events are expected to increase in the future. However, the influence of such extreme events on the connection to nature and the perception of the boundaries of our planet among the people affected has not yet been sufficiently investigated. The few existing studies often provide contradictory results.

In this study, important findings were obtained after the flood disaster in Western Europe in 2021. The survey results indicate that the personal connection to nature did not differ significantly between those who directly experienced an extreme weather event and those who did not. Likewise, perceptions of planetary boundaries did not significantly differ between the groups, implying that the flood event did not cause any significant long-term changes in environmental perceptions.

In the future, longitudinal studies could provide a deeper understanding of how relationships between humans and nature change over time following extreme weather events. By tracking changes in connection to nature and perceptions of the environment at different points in time after an extreme weather event, researchers could more accurately examine when changes occur or are absent. In addition, qualitative studies could help to determine the causes of effects or missing effects in the future. Interdisciplinary studies, for example from sociology and psychology, are particularly suitable for this. The findings from this research contribute to our understanding of how extreme weather events influence human–nature relationships and environmental perceptions. The results provide evidence that connection to nature and perceptions of the environment may be relatively stable among those affected by extreme disasters with natural triggers. However, more research is needed to prove this stability. Possible causes for this stability also need to be explored and this study may provide a starting point for this.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12302-024-00950-5.

Supplementary material 1.

Acknowledgements
The authors would like to thank Patrick Haas and the town of Stolberg for their support with the survey.

Author contributions
MWK designed the study and analyzed and interpreted the data; MWK wrote the first draft of the manuscript; SS contributed to the data collection; CV, OM, SS and TF contributed to the conception of the work and the fundamental revision of the first draft. All authors read and approved the final manuscript. This work is an interdisciplinary collaboration involving authors from different scientific disciplines.

Funding
Open Access funding enabled and organized by Projekt DEAL. The authors have been supported by the RobustNature Excellence Initiative (internal prefunding of Goethe University Frankfurt).

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
As only people of legal age were surveyed, the survey was voluntary and all data were collected anonymously, no approval from the local ethics committee was required.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 28 March 2024 Accepted: 16 June 2024
Published online: 24 June 2024

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Publisher's Note

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