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Public concern about, and desire for research into, the human health effects of marine plastic pollution: Results from a 15-country survey across Europe and Australia

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ABSTRACT

Marine plastic pollution is caused by humans and has become ubiquitous in the marine environment. Despite the widely acknowledged ecological consequences, the scientific evidence regarding detrimental human health impacts is currently debated, and there is no substantive evidence surrounding public opinion with respect to marine plastic pollution and human health. Results from a 15-country survey (n = 15,179) found that both the European and Australian public were highly concerned about the potential human health impacts of marine plastic pollution, and strongly supported the funding of research which aims to better understand its health/wellbeing implications. Multi-level modelling revealed that these perceptions varied across socio-demographic factors (e.g. gender), political orientation, marine contact factors (e.g. marine occupation and engagement in coastal recreation activities) and personality traits (e.g. openness, conscientiousness and agreeableness). Quantifying attitudes, as well as understanding how individual-level differences shape risk perception will enable policy makers and communicators to develop more targeted communications and initiatives that target a reduction in marine plastic pollution.

1. Introduction

The world's seas and oceans face a number of critical threats, ranging from climate change and ocean acidification to marine plastics and overfishing. Plastic pollution in our oceans is one of the fastest growing environmental challenges on the planet (Hamilton et al., 2019; Jambeck et al., 2015; Thevenon et al., 2015), with research indicating the problem may be even worse than previously estimated (Pabortsava and Lampitt, 2020). The United Nation's (UN) decade of Ocean Science for Sustainable Development (2021–2030) presents an opportunity for action to address research gaps in the marine context (UN, n.d.).

Unlike climate change, the anthropogenic nature of the plastic problem has not been challenged (Pahl et al., 2017). Humans are the sole source of plastic pollution, and our decisions and actions are critical for any solutions. 'Macroplastic' pollution (carrier bags, bottles etc.) is highly visible, but there is growing awareness of the problem of 'microplastic' particles (Law and Thompson, 2014; Napper and Thompson, 2019) resulting from the breakdown of larger items, or the discharge of small particles from sources such as clothing fibres (Napper and Thompson, 2016) and car tyres (Boucher and Friot, 2017). There is now extensive evidence of a range of negative plastic impacts on marine wildlife and ecosystems (Gall and Thompson, 2015). The issue of marine plastic pollution has been pushed into the spotlight by a mixture of scientific progress, public discussion and media coverage (e.g. TV

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programmes such as Blue Planet II) leading to the so-called 'Blue Planet II effect' (Keep Britain Tidy, 2019; Thompson, 2019). The combined result is increasing policy responses at the global level (European Commission, 2018; G20, 2019; Ocean Plastics Charter, 2018; UNEP, 2018).

The impacts on human health, however, remain unclear and the need for research in this area has been identified as a priority (Scientific Advice for Policy European Academies [SAPEA], 2019; Vethaak and Legler, 2021; World Health Organization [WHO], 2019). There is also a critical lack of high quality data regarding public concerns about the potential impacts of marine plastic pollution on human health, and the desire for actions, including more research into the potential health effects. Although there have been widespread media reporting and NGO campaigns discussing (potential) adverse effects of plastic pollution on human health, we know little about whether this is reflected in public concern (SAPEA, 2019). Are the public concerned, despite our current lack of knowledge, or are they more focused on better understood threats such as oil/chemical spills, or climate change related impacts on sea level rise, ocean acidification and storms/floods (Stafford and Jones, 2019)? Although public concern has been stated to motivate policy we also know little about public support for research into the effect of plastics on human health (SAPEA, 2019). The aim of the current research was to use data from a representative 15-country survey across Europe and Australia to investigate these knowledge gaps and the role of several predictors derived from relevant theoretical approaches.

1.1. The issue of plastic pollution

Plastic has many societal benefits (Andrady and Neal, 2009). However, at production levels of approximately 320 million tonnes per year, 40% of which is single-use packaging, there has, and continues to be, enormous quantities of plastic waste (Thompson et al., 2009; Wright and Kelly, 2017). It is estimated that approximately 60% of all plastic ever produced globally has been discarded, either accumulating in landfill or in the environment (Geyer et al., 2017). Estimates indicate, for instance, that 4.8 to 12.7 million metric tonnes of plastic waste entered the ocean in 2010 alone (Jambeck et al., 2015). Due to its longevity, plastic pollution causes not only aesthetic impacts for coastlines, but has serious consequences for marine species (Gall and Thompson, 2015; UNEP, 2016).

Combating plastic pollution has become increasingly important at national and transnational policy levels. For example, the European Union (EU) Plastics Strategy (European Commission, 2018) aims towards a more 'circular economy' through setting targets to reduce plastic waste and increase recycling. Policies have also been rapidly introduced across many countries that target behaviours and social practices, e.g., plastic bag charges or taxes (Nielsen et al., 2020). As of July 2018, 127 countries had introduced some form of regulation on plastic bags (UNEP, 2018), with research indicating that support for such policies has increased and can lead to a 'policy spillover' effect, yielding enhanced support for other plastic reducing policies (Thomas et al., 2019). The G20 have agreed to tackle marine plastic pollution at a global scale (G20, 2019).

The European Commission's SAPEA report on Microplastics in Nature and Society (2019) points out that although plastic pollution could potentially cause problems in the future if current pollution is sustained, the evidence regarding the human health impacts of plastic pollution is currently inconclusive. Furthermore, the WHO (2019) report on Microplastics in Drinking-Water suggests that although they do not pose a sufficient risk to human health at current levels, further research is needed to assess exposure to microplastics both via drinking water and the wider environment. This lack of empirical research was highlighted by a recent systematic mapping review of research on the links between the marine environment and human health (Short et al., 2021). The present research takes a theoretical approach based on the risk perception literature, which stresses the central role of subjective concern or worry and investigates different types of variables to explain the level of public concern. These variables include socio-demographic variables (e.g., gender), political orientation, contact/experience with the hazard and its context, and psychological factors such as personality. Personality factors and political orientation have recently attracted attention in the context of risk perception, for example with climate change, but we know of no research that has investigated this for plastic risk perception.

1.2. Public perceptions of marine plastic pollution

In terms of public perceptions and concerns, a 2014 Eurobarometer survey showed that those who lived in EU member state countries (93% of those sampled) agreed that "*more initiatives are needed by the public authorities to limit the presence of plastic waste in the environment*" (European Commission, 2014, p. 15). However, there has been little multi-country research unpacking these kinds of headline findings in detail with respect to the marine environment in particular (Heidbreder et al., 2019). Where the necessary kind of multiple country studies of public perceptions of the health of marine ecosystems have been conducted (e.g. Gelcich et al., 2014; Potts et al., 2016; see also Lotze et al., 2018), these tended to focus on broader threats such as climate change, industrial pollution and over-fishing and did not look at plastics. Moreover, the focus has tended to be on marine rather than human health.

The only international study we are aware of that did touch on the human health implications of 'marine litter' (although not plastics directly, 80% of marine litter is estimated to be plastic [IUCN, 2018]) was conducted by Hartley et al. (2018). Of particular relevance here, participants were asked how much threat they felt marine litter was to five different domains: the marine environment, the appearance of the coast, tourism, shipping, and crucially, human health. Participants ranked the marine environment as being most threatened and human health as third.

1.3. Potential predictors of public concerns about marine plastic pollution

Of further relevance, Hartley et al. (2018) used hierarchical regression analyses to predict concern about marine litter, building models with three predictor groups: a) demographics (e.g. age, gender, education level), b) coastal access and experience (e.g. home proximity to the coast, visit frequency), and c) psychological factors (e.g. values). Understanding the role of these factors helps to predict levels of concern and is critical in developing subsequent communication and engagement strategies as well as potential policy developments (Potts et al., 2016).

In terms of demographics, the literature suggests several factors consistently predict concern about different environmental issues, and thus may also predict plastic pollution concern and beliefs. Women, for instance, tend to be more concerned than men about a range of threats (Zelezny et al., 2000), including pollution (Potts et al., 2016). People with higher educational attainment also tend to exhibit greater environmental concern in general (Gifford and Nilsson, 2014), as well as for marine pollution (European Commission, 2020a) and marine litter in particular (Hartley et al., 2018). However, while most studies suggest that younger people tend to be more concerned about environmental issues generally (Gifford and Nilsson, 2014; Van Liere and Dunlap, 1980), Potts et al. (2016) found that older adults (46–64 years) were more concerned about ocean health compared to younger adults (≤27 years), possibly indicating something unique about the marine environment that warrants further investigation. Moreover, the 2017 Eurobarometer data (European Commission, 2017) found that older participants were also more worried about the impact of every day plastic products on health. When combined with the results of Potts et al. (2016), this suggests that older adults may be especially concerned about plastics in the marine environment.

Moreover, political orientation has been found to be linked to perceptions of environmental issues. People on the political left (Democrats, Liberals etc.) tend to be more concerned about environmental issues such as climate change (Hornsey et al., 2016) and marine threats such as beach pollution, overfishing and sea level rise (Hamilton and Safford, 2015), than those on the political right (Republicans, Conservatives etc.). The strength of political orientations effects on climate change concern has been shown to vary across countries (Poortinga et al., 2019). Additionally, cross-national survey analysis has shown that the relationship between conservatism and environmental concern is reversed in some less developed countries and countries with poor environmental quality, with conservatives expressing more environmental concern than liberals (Nawrotzki, 2012).

Contact with the marine environment is of particular importance in the present study. Both Europe and Australia have large coastal populations (Clark and Johnston, 2016; European Environment Agency, 2020), and it is theorized that contact with the marine environment (defined broadly) will increase exposure to (and therefore visibility of) marine plastic pollution, which will influence concern. Contact with the marine environment, e.g. home proximity and recreational visits, has also been found to be a predictor of concern about both climate change and ocean related issues. Milfont et al. (2014) found that people in New Zealand who live closer to the coast had greater concerns about climate change and supported governmental regulation of carbon emissions more. Climate change concerns were not, however, related to living closer to the coast in a sample of Florida students (Carlton and Jacobson, 2013) or in the Potts et al. (2016) multi-European country survey. However, Potts et al. (2016) found that people who lived closer to the coast were more concerned about the health of the world's ocean in some of the countries sampled. In terms of recreational visits, Gelcich et al. (2014) found that regular coastal visitors reported being more informed and concerned about all threats to the marine environment (including 'pollution'). Similarly, Hartley et al. (2018) found that the frequency of coastal visits and noticing litter more frequently on visits were positively related to greater concern for the impacts of marine litter. These findings are consistent with other literature which suggests that coastal dwellers may be more pro-environmental in general (Alcock et al., 2020), though we know of no studies that have explored the relationships between coastal proximity and visit frequency and support for research into marine plastic pollution in particular.

Finally, the present study aims to extend the previous literature by including a novel psychological element, personality, in the context of public perceptions of plastic pollution. Individual personality traits have previously been found to predict concern about environmental issues in general. The 'Big Five' model of personality proposes five dimensions: openness, conscientiousness, extraversion, agreeableness and neuroticism (McCrae and John, 1992). Higher levels of openness, conscientiousness and agreeableness and lower levels of neuroticism and extraversion have been associated with greater appreciation of the environment (Milfont and Sibley, 2012), whilst greater environmental concern has been predicted by higher levels of openness and agreeableness, but also higher levels of conscientiousness and neuroticism (Hirsh, 2010). These findings may be related to Schwartz's (1994) theory of basic values. Specifically the value of self-transcendence, which incorporates universalism and benevolence, both related to care for others and for the environment, has been shown to be related to openness and agreeableness (Hirsh, 2010; Olver and Mooradian, 2003). A recent meta-analysis also found openness to have the strongest association with pro-environmental attitudes, as well as conscientiousness, agreeableness and extraversion to a lesser extent. However, no association was found between neuroticism and environmental attitudes (Soutter et al., 2020).

We know of no research looking into the relationships between personality traits and perceptions of any marine environmental issues, including marine plastic pollution. Personality traits are of particular interest in the current study focused on health risks, as they have been shown to influence likelihood of engaging in risky health behaviours (Nicholson et al., 2005; Vollrath and Torgersen, 2002) and perceived susceptibility of future health risks (Vollrath et al., 1999). Moreover, agreeableness, conscientiousness and neuroticism have been shown to be the most consistent personality traits for predicting perceived susceptibility. Both agreeableness and conscientiousness were negatively associated with perceived susceptibility of health risks, possibly indicating an optimism about future health risks and lower concern, whilst neuroticism has been positively associated with perceived susceptibility to future health risks, possibly indicating greater concern about health risks (Vollrath et al., 1999). However, significance of effects differed depending on the type of health risk considered. Importantly we know of no previous research which has studied the link between personality and health risk perceptions related to the environment (e.g. marine pollution).

1.4. Aims of this paper

The current research aimed to fill these research gaps using a 15 country online survey similar to that of researchers interested in both climate change concerns (e.g. Bouman et al., 2020; Poortinga et al., 2019), and concerns about changes in the marine environment (Gelcich et al., 2014; Hartley et al., 2018; Potts et al., 2016). The survey was part of a larger EU project called Seas, Oceans and Public Health in Europe (SOPHIE, www.SOPHIE2020.eu), the aim of which was to design a strategic research agenda around oceans and human health for the European Union (EU). The 'SOPHIE survey' was designed to add the public's voice to this research agenda setting, which may otherwise be dominated by experts and active stakeholders. Additional funding enabled the inclusion of survey participants from Australia to provide a perspective beyond Europe (i.e. Seas, Oceans and Public Health in Australia – SOPHIA, survey).

The current paper focused specifically on perceptions of marine plastic pollution in relation to potential human health and wellbeing impacts, investigating stated concerns and desire for future research funding (Gelcich et al., 2014; SAPEA, 2019). Our research questions were: RQ1) How concerned are the public about the human health/wellbeing effects of marine plastic pollution in comparison to 15 other potential marine threats?; RQ2) To what extent does the public support more research funding into understanding the health/wellbeing implications of marine plastic pollution?; RQ3) Do socio-demographic, political orientation, contact/experience, and personality factors significantly predict levels of concern (RQ3a) and support for research funding (RQ3b) regarding the effects of marine plastic pollution on human health?; and RQ4) To what extent does concern mediate any impact of socio-demographic, political orientation, contact/experience, and personality factors on preferences for further research? The ultimate aim was to feed the survey results into the SOPHIE strategic research agenda (H2020 SOPHIE Consortium, 2020), to ensure that public perceptions were represented.

2. Methods

2.1. The SOPHIE & SOPHIA surveys

A total of 15,179 individuals (M_{age} = 46.20, age range: 18–99 years, 7390 men and 7789 women) participated in the surveys, with approximately 1000 respondents from each of 15 countries (Australia, Belgium, Bulgaria, Czech Republic, France, Germany, Greece, Italy, the Netherlands, Norway, Poland, Portugal, the Republic of Ireland, Spain and the United Kingdom) broadly representative of the population. Median completion time was 18 min. The 14 European countries were selected to ensure inclusion of at least one country bordering one of each of Europe's six sea basins (i.e. Atlantic Ocean, Baltic Sea, Black Sea, Mediterranean, North Sea and Arctic), with the exception of the Czech Republic, which was included as a land-locked comparison. The international polling company, YouGov, was commissioned to deliver the survey via their online panels from March to April 2019 (Europe), and in September 2019 (Australia), with country-level stratified sampling to ensure respondent representativeness by age, gender and region. Further details of survey development are reported in Supplementary Materials S1.

2.2. Measures

2.2.1. Dependent variables

A list of the marine threats and areas for further research for which respondents were asked to indicate their attitudes is shown in Table 1. The topics and phrasing in column A and B are not identical due to the consultative process with experts and stakeholders during survey development. However, the topic of interest here, marine plastic pollution, is present in both columns and worded exactly the same.

Concern was assessed by asking respondents: "*How concerned do you feel about the following potential threats to human health/wellbeing*?" (Table 1; column A). Responses were recorded on a 7-point scale, from 0 ("not at all concerned") to 6 ("extremely concerned").

Support for research was assessed by asking respondents: "*To what extent would you support more research funding in the following areas, to better understand health/wellbeing implications? Research into…*" (Table 1; column B). Responses were recorded on a 7-point scale, from 0 ("*no support at all*") to 6 ("*strong support*").

The order in which the threats and research areas appeared were randomised for each respondent. Respondents were also provided with the response options "*don't know*" and "*prefer not to answer*" throughout, which were recorded as 'missing'.

Table 1
Marine threats and research areas covered by the surveys in relation to human health impacts/implications.

	A) Marine threats		*B) Marine research areas*
1	Human and animal sewage in bathing waters*	1	Bathing water quality*
2	Sea-level rise	2	Coastal protection/ defences
3	Loss of marine biodiversity/ species	3	Marine species/ wildlife protection
4	Ocean acidification (caused by CO2 being absorbed into the ocean, making the water more acidic)	4	Marine-climate change issues
5	Plastic pollution of marine waters	5	Plastic pollution in marine waters
6	Coastal overdevelopment (homes, hotels etc.)	6	The health/ wellbeing effects of living near the coast
7	Sunburn & sunstroke on coastal visits	7	Education and awareness raising
8	Drowning from recreational activities	8	The health/ wellbeing effects of spending leisure time in and around marine environments
9	Collapse of fish stocks	9	Sustainable aquaculture
10	Jellyfish swarms	10	Jellyfish swarms and algal overgrowth
11	*Increased frequency of harmful algae (toxic blue-green algae, red tides etc.)*	*11*	*Biotechnology from marine organisms (medicines, cosmetics etc.)*
12	*Invasive (non-native) marine species introduced by humans into new marine locations*	*12*	*Marine renewable energy*
13	*Emergence of drug-resistant microbes in seawater*	*13*	*Sustainable shipping (electric ships etc.)*
14	*Contamination of seafood*	*14*	*Deep-sea mining*
15	*Chemical/ oil pollution of marine waters*	*15*	*Behaviour change to improve health/ wellbeing*
16	*Flooding and storms*		

Note: Topic order was randomised for each participant, so numbers are purely for explanatory purposes for the graphs below. The marine topic of interest, marine plastic pollution, is highlighted by the grey box. Marine threats and marine research areas that are not matched are italicised. *'Bathing waters' was substituted for 'ocean swimming area' for the Australian survey, which also asked about human and animal sewage separately. In order to aid comparison with EU respondents, a mean was taken of responses to both threats, but this comparison needs to be treated with caution.

2.2.2. Predictor variables

There were three groups of predictor variables (socio-demographics and political orientation, contact/experience, personality) which were entered into models predicting a) concern (RQ3a) and b) research support (RQ3b; Table S1). Due to space constraints further specifics and justification for inclusion of all variables is provided in Table S1 of the Supplementary Materials document.

2.3. Data analysis

Data were analysed using the statistical programme R (version 3.6.1; R Core Team, 2019). The R code for the following data analysis is available on Mendeley data (https://doi.org/10.17632/sxmtz2m57f.1). To explore relative concern about marine plastics for public health (RQ1), we used the package 'sjstats' (Lüdecke, 2020) to calculate the weighted means and 95% Confidence Intervals (CIs) for each threat across all countries combined, as well as for each country individually. Visually ordering the threats from lowest to highest concern facilitates threat comparison, as a lack of overlap in CIs is indicative of significant differences. We were particularly interested in the ranking of concern about marine plastics relative to other threats and which threats were perceived to be of significantly lower vs. higher concern. To formally test if type of marine threat had a significant effect on the level of concern expressed, a repeated measures Analysis of Variance (ANOVA) was conducted via a linear mixed effects model using the 'lme4' package (Bates et al., 2015). The ANOVA, whose output was printed via the 'stats' package (R Core Team, 2019), returned an F value from a likelihood ratio test. Post hoc comparisons were then retrieved via the package 'emmeans' (Lenth, 2020). The same approach was used to explore preferences for research funding (RQ2).

To explore individual differences in concern about the health impacts of marine plastic pollution (RQ3a) and preferences for research into their human health impacts (RQ3b), we conducted a series of linear mixed effects models using the 'lme4' package (Bates et al., 2015). Country of residence was included as a random intercept and following previous environmental concern literature (Nawrotzki, 2012; Poortinga et al., 2019), political orientation as a random slope, to account for national-level respondent clustering and cross-country variation in the effect of political orientation on concern and research support. For the purpose of the multilevel models, political orientation was categorized into four groups to ensure that the 2381 respondents who answered "don't know" or "prefer not to answer" could be retained in the analysis. Further details of the categorization is contained in Table S1 of the Supplementary Materials document. Survey weights were applied to ensure national representativeness with regards to the sampling strata within each country (i.e. sex, age, and region of residence). 'Missing' categories were created for several variables to enable the inclusion of participants who chose not to answer all questions in analyses and thereby maintain overall representativeness.

To answer RQ3a (Model 1) and RQ3b (Model 2), models were built in stages, with each stage adding a new set of variables, until we ended with a full model which included all variables. Variables added to the models were as follows: Model a – socio-demographics plus political orientation only; Model b – model a plus marine contact/experience variables, i.e. coastal proximity, visit frequency, recreational activities and occupation; Model c – model b plus personality traits.

RQ4 concerning the possible mediating effects of concern for marine plastic pollution on any relationships between predictor variables and research funding preferences, was investigated in two steps. First, we added 'concern' as a further variable to the model predicting research preferences in Model 2d. If concern is a significant predictor of research preferences and the strength of any associations with other predictors falls, this would be indicative of possible mediation. To explore this possibility further, formal mediation analysis was conducted, using the R package 'mediation' (Tingley et al., 2014) which was able to disaggregate the total effects of any socio-demographic predictors etc. into direct effects and indirect effects through concern.

Hierarchical models were compared using the 'ANOVA' function of the package 'stats' (R Core Team, 2019). This specified if the variables added in successive models significantly improved the Chi-square statistic and therefore the model fit. Using the 'ANOVA' function involved reducing the sample size of each model so that they were the same as the final model.

3. Results

3.1. Public concern

Respondents were more concerned about the human health impact of marine plastic pollution ($M = 5.45$; $SD = 1.04$) than any other threat (Fig. 1). Repeated measures ANOVA found that concern differed significantly between marine threats ($F(15, 218{,}945) = 3546.60$; $p < 0.001$); and post-hoc Tukey HSD comparisons demonstrated that concern for plastic was higher than concern for all other threats including the second highest concern, chemical and oil pollution ($M = 5.36$; $SD = 1.09$; $p < 0.001$).

At the specific country level (Fig. 2), plastic pollution was the top concern across all countries with the exception of Greece and Poland, where it was second after chemical/oil pollution.

3.2. Public support for research funding

Support for research funding into the health and wellbeing implications of marine plastic pollution was high ($M = 5.07$; $SD = 1.52$), although support for research into the protection of marine species and wildlife was even higher ($M = 5.15$; $SD = 1.21$; Fig. 3). Specifically, the level of support varied by marine research area (ANOVA $F(14, 201{,}194) = 2697.40$; $p < 0.001$). Tukey HSD post hoc comparisons showed that support for research into marine plastic pollution was lower than support for research into the protection of marine species ($p < 0.001$), but higher than support for the next highest ranked issue of coastal protection and defences ($M = 4.95$; $SD = 1.29$; $p < 0.001$).

Nevertheless, six countries (Belgium, Germany, Republic of Ireland, Norway, the Netherlands, and the UK) rated understanding the health effects of marine plastic pollution as their top research funding priority (Fig. 4).

3.3. Predicting concern for the public health/wellbeing impacts of marine plastic pollution

Table 2 shows the three models predicting concern for the human health and wellbeing impacts of marine plastic pollution, averaged across the whole sample but controlling for country using a random intercepts term and using political orientation as a random slope. Model 1a (socio-demographics plus political orientation) suggests that concern about marine plastic pollution increased by 0.18 (95% CIs: 0.16, 0.20) points on the 7-point response scale (i.e. a 2.6% increase) for each additional year in age (starting at age 18). Further, concern about marine plastic pollution was higher for females than males ($\beta = 0.21$, 95% CIs: 0.18, 0.25). Those with a degree-level education were slightly less concerned than those without a degree ($\beta = -0.04$, 95% CIs: -0.07, -0.003). Students ($\beta = 0.09$, 95% CIs: 0.02, 0.17) and those with an 'other' type of employment ($\beta = 0.05$, 95% CIs: 0.003, 0.09) expressed greater concern than did people in employment. There was no association with income. Finally, people with centrist ($\beta = -0.15$, 95% CIs: -0.23, -0.07) and right-leaning ($\beta = -0.22$, 95% CIs: -0.33, -0.12) political orientations exhibited lower concern than those with left-leaning orientations.

Adding marine contact/experience variables in Model 1b had little effect on socio-demographic and political orientation findings, but resulted in an improvement in the model 1a ($\chi^2 = 366.82$; $p < 0.001$). There was, however, no association between home proximity to the

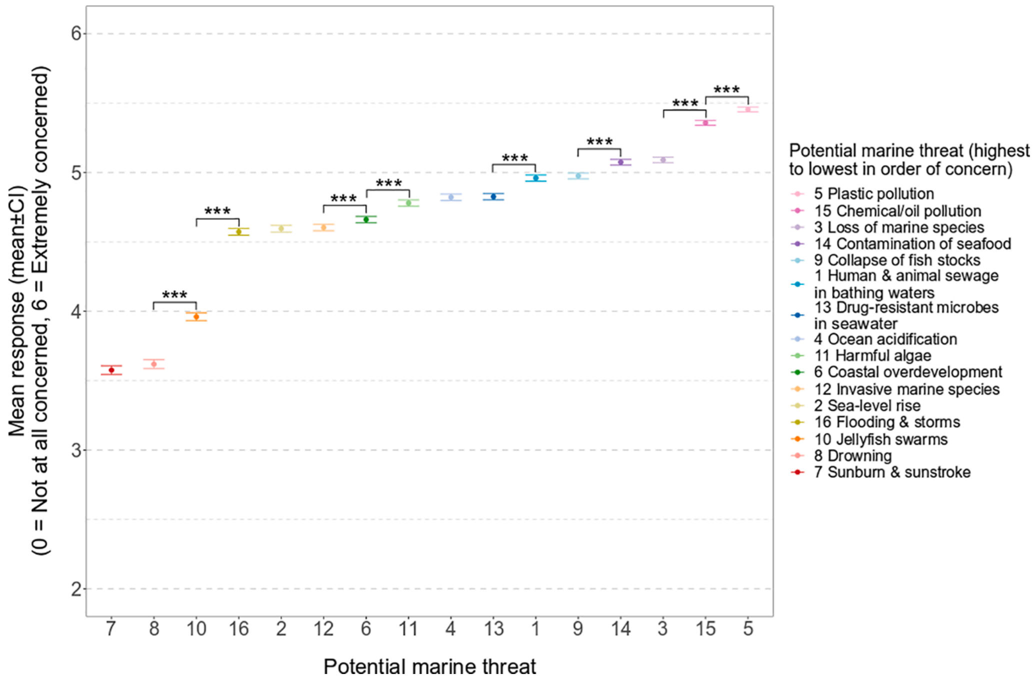

Fig. 1. Mean level of concern (and 95% CIs) for the public health/wellbeing effects of the 16 marine threats. ***p < 0.001.

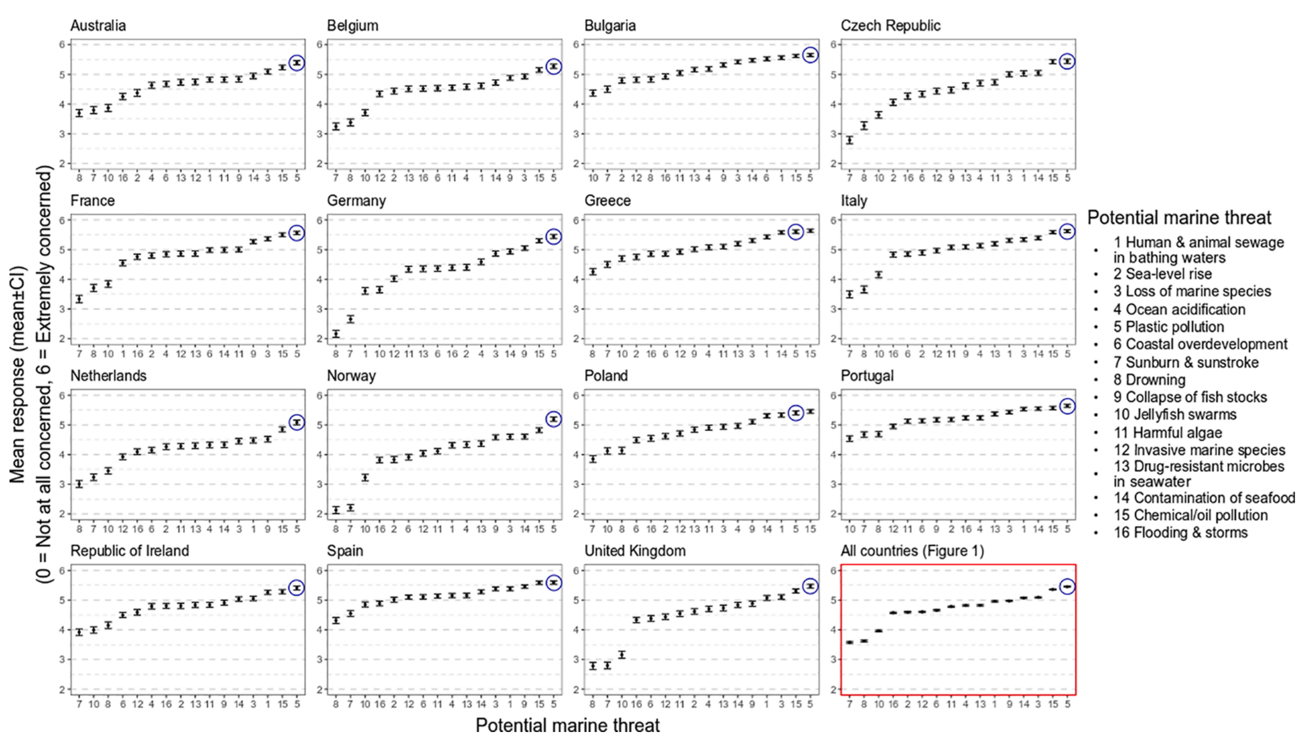

Fig. 2. A country breakdown of mean concern (and 95% CIs) for the 16 marine threats with plastic pollution indicated by circle.

coast and concern for marine plastics and human health. Nevertheless, people who visited the coast ≥ once a week had 1.1% higher marine plastic concern ratings than those who visited less frequently ($\beta = 0.08$, 95% CIs: 0.02, 0.13). Compared to people who did not visit the coast for recreation, people who engaged in land-based coastal activities such as walking (i.e. active coastal recreation activities, $\beta = 0.19$, 95% CIs: 0.15, 0.24), sunbathing/picnics (i.e. passive coastal recreation activities $\beta = 0.17$, 95% CIs: 0.12, 0.22) and eating seafood ($\beta = 0.11$, 95% CIs: 0.08, 0.15) were more concerned about plastic pollution for health than people who engaged in water-based coastal recreation activities such as watersports ($\beta = -0.01$, 95% CIs: -0.05, 0.03) and swimming ($\beta = 0.01$, 95% CIs: -0.03, 0.05). Finally, people who lived in households where at least one person worked in the marine sector had lower concern than those who did not ($\beta = -0.11$, 95% CIs: -0.17, -0.05).

Model 1c added the personality sub-scales, which again improved overall explanatory power ($\chi^2 = 100.26$; $p < 0.001$). Concern was positively associated with openness, suggesting that concern increased by 0.05 (95% CIs: 0.03, 0.07) points on the 7-point response scale (i.e.

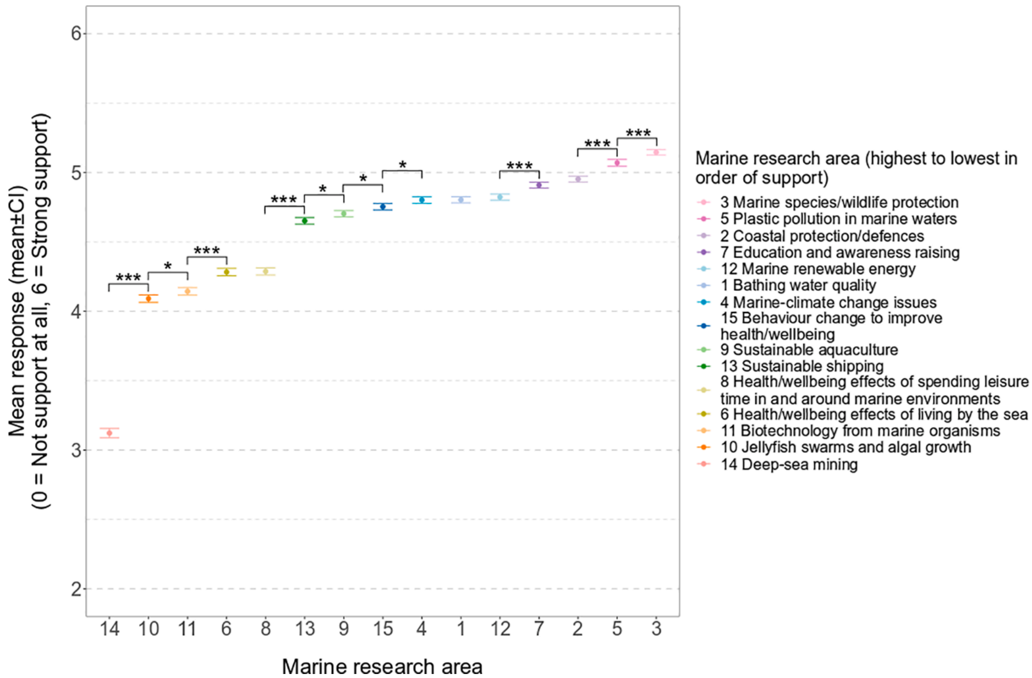

Fig. 3. Mean level of research funding support (and 95% CIs) for 15 marine research areas. ***p < 0.001, **p < 0.01, *p < 0.05.

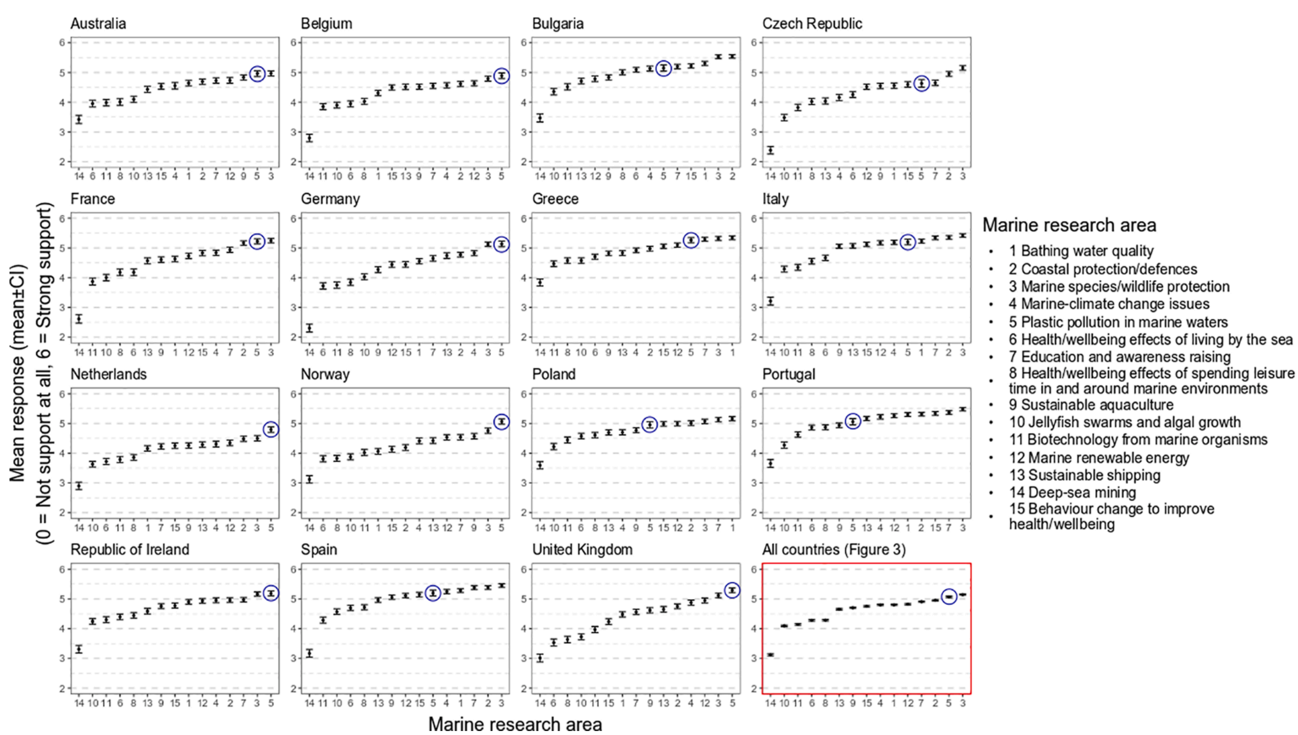

Fig. 4. Country level breakdown of support (and 95% CIs) for research funding with marine plastics indicated with a circle.

0.7% increase) for each additional unit increase in openness. Additionally, concern was positively associated with conscientiousness ($\beta = 0.04$, 95% CIs: 0.02, 0.06) and agreeableness ($\beta = 0.06$, 95% CIs: 0.04, 0.08). However, extraversion and neuroticism were unrelated. The previous effects from Model 1b remained the same, with the exception of 'being a student', which no longer yielded a significant effect. The final model explained 11% of the variance in concern.

3.4. Predicting support for research funding in marine plastic pollution

3.4.1. Multi-level linear regression analysis

Table 3 shows the four models predicting support for research funding to better understand the human health implications of marine plastic pollution across all 15 countries. Model 2a (socio-demographics plus political orientation) shows that support for research funding into plastic pollution increased by 0.16 (95% CIs: 0.13, 0.19) points on the 7-point scale, equivalent to a 2.3% increase in support, for each additional

Table 2
Multi-level regression analysis predicting concern for the public health impacts of marine plastic pollution with 'country' as a random intercept, and 'political orientation' as a random slope (Model 1a – c).

	Model 1a Socio-demographic factors and political orientation	Model 1b Marine contact/experience variables added	Model 1c Personality traits added
	B (95% CI)	*B (95% CI)*	*B (95% CI)*
(Intercept)	5.46 (5.40, 5.52)***	5.12 (5.05, 5.20)***	4.59 (4.44, 4.73)***
Age (18 to 99)	0.18 (0.16, 0.20)***	0.17 (0.14, 0.19)***	0.16 (0.13, 0.18)***
Gender: female (vs. male)	0.21 (0.18, 0.25)***	0.19 (0.16, 0.22)***	0.18 (0.15, 0.21)***
Education: degree (vs. no degree)	−0.04 (-0.07, -0.003)*	−0.06 (-0.09, -0.03)***	−0.06 (-0.10, -0.03)***
Education: missing (vs. no degree)	0.01 (-0.29, 0.32)	0.07 (-0.23, 0.37)	0.10 (-0.20, 0.40)
Employment: student (vs. full-time employment)	0.09 (0.02, 0.17)*	0.08 (0.0004, 0.15)*	0.07 (-0.004, 0.15)
Employment: retired (vs. full-time employment)	0.03 (-0.03, 0.08)	0.04 (-0.01, 0.10)	0.05 (-0.003, 0.11)
Employment: other (vs. full-time employment)	0.05 (0.003, 0.09)*	0.06 (0.01, 0.10)*	0.06 (0.01, 0.10)*
Employment: missing (vs. full-time employment)	−0.39 (-0.54, -0.24)***	−0.31 (-0.46, -0.16)***	−0.31 (-0.46, -0.16)***
Income: low (vs. middle)	−0.02 (-0.06, 0.03)	0.01 (-0.04, 0.06)	0.02 (-0.03, 0.06)
Income: high (vs. middle)	0.03 (-0.01, 0.07)	0.01 (-0.03, 0.05)	0.00 (-0.04, 0.05)
Income: missing (vs. middle)	0.03 (-0.02, 0.08)	0.04 (-0.02, 0.09)	0.03 (-0.02, 0.09)
Political orientation: centre (vs. left)	−0.15 (-0.23, -0.07)**	−0.14 (-0.22, -0.07)**	−0.14 (-0.21, -0.07)***
Political orientation: right (vs. left)	−0.22 (-0.33, -0.12)***	−0.21 (-0.31, -0.11)***	−0.21 (-0.30, -0.11)***
Political orientation: missing (vs. left)	−0.11 (-0.20, -0.02)*	−0.08 (-0.17, 0.004)	−0.08 (-0.16, 0.002)
Coastal proximity: ≤1km (vs. + 20 km)		0.004 (-0.07, 0.07)	−0.001 (-0.07, 0.07)
Coastal proximity: >1–5 km (vs. + 20 km)		−0.04 (-0.10, 0.02)	−0.04 (-0.10, 0.02)
Coastal proximity: >5–20 km (vs. + 20 km)		−0.03 (-0.08, 0.02)	−0.04 (-0.09, 0.01)
Coastal proximity: missing (vs. + 20 km)		0.05 (-0.17, 0.27)	0.06 (-0.16, 0.27)
Visit frequency: once a week or more (vs. less often than once a week)		0.08 (0.02, 0.13)**	0.07 (0.01, 0.12)*
Visit frequency: missing (vs. less often than once a week)		−0.001 (-0.12, 0.12)	0.001 (-0.12, 0.12)
Recreation activities: active (vs. none)		0.19 (0.15, 0.24)***	0.19 (0.14, 0.24)***
Recreation activities: passive (vs. none)		0.17 (0.12, 0.22)***	0.16 (0.11, 0.21)***
Recreation activities: watersports (vs. none)		−0.01 (-0.05, 0.03)	−0.01 (-0.05, 0.03)
Recreation activities: swimming (vs. none)		0.01 (-0.03, 0.05)	0.01 (-0.03, 0.04)
Recreation activities: eating seafood (vs. none)		0.11 (0.08, 0.15)***	0.11 (0.07, 0.14)***
Recreation activities: other (vs. none)		0.35 (0.19, 0.50)***	0.34 (0.19, 0.49)***
Recreation activities: missing (vs. none)		−0.50 (-0.81, -0.18)**	−0.48 (-0.79, -0.17)**
Marine occupation: household member has a marine occupation (vs. no marine occupation)		−0.11 (-0.17, -0.05)***	−0.10 (-0.16, -0.05)***
Marine occupation: missing (vs. no marine occupation)		−0.21 (-0.30, -0.13)***	−0.21 (-0.30, -0.12)***
Personality: openness (1 to 5)			0.05 (0.03, 0.07)***
Personality: conscientiousness (1 to 5)			0.04 (0.02, 0.06)***
Personality: extraversion (1 to 5)			0.01 (-0.01, 0.03)
Personality: agreeableness (1 to 5)			0.06 (0.04, 0.08)***
Personality: neuroticism (1 to 5)			0.01 (-0.01, 0.03)
N	14,593	14,593	14,593
N (country)	15	15	15
AIC	41875.90	41539.09	41448.82
χ^2		366.82***	100.26***
R2 (fixed)	0.05	0.08	0.09
R2 (total)	0.08	0.10	0.11

Note: *** $p < 0.001$, **$p < 0.01$, *$p < 0.05$. CI = confidence interval.

year in age (starting at age 18). Additionally, females ($\beta = 0.18$, 95% CIs: 0.13, 0.23), those with a degree level education ($\beta = 0.07$, 95% CIs: 0.02, 0.12) and students ($\beta = 0.14$, 95% CIs: 0.03, 0.26) all expressed greater levels of support in comparison to males, those without a degree education level and those in full-time employment. Those in the low income category (β = -0.09, 95% CIs: -0.16, -0.02) and those who identified as centre leaning politically (β = -0.18, 95% CIs: -0.29, -0.07) and right-leaning politically (as opposed to left-leaning) (β = -0.26, 95% CIs: -0.38, -0.15) expressed lower levels of support.

Adding marine contact/experience variables improved the model (Model 2b, $\chi^2 = 242.98$; $p < 0.001$), though the effect of having a degree level education and having a low income was no longer significant (suggesting possible mediation). Neither coastal proximity, nor visit frequency was found to be related to research support in model 2b. However, those who engaged in active coastal recreation activities (β = 0.20, 95% CIs: 0.12, 0.27), reported greater levels of support (i.e. equivalent to a 2.9% increase compared to no coastal recreation). Additionally, those who engaged in passive coastal recreation activities ($\beta = 0.17$, 95% CIs: 0.09, 0.25), eating seafood ($\beta = 0.14$, 95% CIs: 0.09, 0.19) and in other types of activities ($\beta = 0.43$, 95% CIs: 0.20, 0.67) did express greater levels of support. Those who engaged in watersports and swimming did not support research funding more than those who did not visit the coast for recreation. Echoing the concern results, those who worked in a marine occupation (or who had a household member in a marine occupation) reported less support than others (β = -0.12, 95% CIs: -0.21, -0.03).

Adding personality traits as predictors improved the model further (Model 2c $\chi^2 = 40.43$; $p < 0.001$). However, the coefficients reveal that the effects of personality were relatively small. Taking the example of openness, support for research funding increased by 0.05 (95% CIs: 0.02, 0.08) points on the 7-point scale, an 0.7% increase in support, for each unit increase in openness. Likewise, conscientiousness ($\beta = 0.04$, 95% CIs: 0.01, 0.07) and agreeableness ($\beta = 0.04$, 95% CIs: 0.01, 0.08) were positive predictors of research support, but extraversion ($\beta = 0.01$, 95% CIs: -0.02, 0.03) and neuroticism ($\beta = 0.02$, 95% CIs: -0.01, 0.04) yielded no significant effect.

Finally, Model 2d added concern for the human health impacts of marine plastic pollution as a predictor variable to the model, resulting in the most significant improvement ($\chi^2 = 2358.19$; $p < 0.001$). Concern about marine plastic pollution was a strong predictor of research preferences (β = 0.59, 95% CIs: 0.57, 0.61), suggesting that support for research funding increased by 0.59 (95% CIs: 0.57, 0.61) points on the 7-

Table 3
Multi-level regression analysis predicting support for research funding into understanding the health and wellbeing implications of marine plastic pollution, with a random intercept of 'country' and random slope of 'political orientation' (Model 2 – d).

	Model 2a Socio-demographic factors and political orientation	Model 2b Marine contact/experience variables added	Model 2c Personality traits added	Model 2d Concern added
	B (95% CI)	*B (95% CI)*	*B (95% CI)*	*B (95% CI)*
(Intercept)	5.13 (5.05, 5.20)***	4.71 (4.57, 4.85)***	4.23 (3.98, 4.47)***	1.53 (1.28, 1.78)***
Age (18 to 99)	0.16 (0.13, 0.19)***	0.15 (0.11, 0.18)***	0.14 (0.10, 0.17)***	0.05 (0.02, 0.08)**
Gender: female (vs. male)	0.18 (0.13, 0.23)***	0.15 (0.10, 0.20)***	0.14 (0.09, 0.19)***	0.04 (-0.01, 0.09)
Education: degree (vs. no degree)	0.07 (0.02, 0.12)**	0.04 (-0.01, 0.09)	0.04 (-0.02, 0.09)	0.07 (0.02, 0.12)**
Education: missing (vs. no degree)	0.26 (-0.20, 0.72)	0.31 (-0.15, 0.76)	0.33 (-0.12, 0.79)	0.28 (-0.14, 0.70)
Employment: student (vs. full-time employment)	0.14 (0.03, 0.26)*	0.12 (0.01, 0.24)*	0.12 (0.00, 0.23)*	0.08 (-0.03, 0.19)
Employment: retired (vs. full-time employment)	−0.02 (-0.10, 0.06)	−0.003 (-0.08, 0.08)	0.01 (-0.08, 0.09)	−0.03 (-0.10, 0.05)
Employment: other (vs. full-time employment)	−0.01 (-0.07, 0.06)	0.01 (-0.06, 0.07)	0.001 (-0.07, 0.07)	−0.03 (-0.10, 0.03)
Employment: missing (vs. full-time employment)	−0.25 (-0.48, -0.03)*	−0.15 (-0.38, 0.08)	−0.15 (-0.37, 0.08)	0.03 (-0.18, 0.24)
Income: low (vs. middle)	−0.09 (-0.16, -0.02)*	−0.06 (-0.13, 0.01)	−0.06 (-0.13, 0.01)	−0.07 (-0.13, -0.01)*
Income: high (vs. middle)	0.05 (-0.01, 0.11)	0.05 (-0.02, 0.11)	0.04 (-0.02, 0.10)	0.04 (-0.02, 0.09)
Income: missing (vs. middle)	−0.08 (-0.16, -0.0001)*	−0.07 (-0.15, 0.02)	−0.07 (-0.15, 0.01)	−0.09 (-0.17, -0.02)*
Political orientation: centre (vs left)	−0.18 (-0.29, -0.07)*	−0.14 (-0.21, -0.07)***	−0.13 (-0.23, -0.03)*	−0.06 (-0.13, 0.02)
Political orientation: right (vs. left)	−0.26 (-0.38, -0.15)***	−0.22 (-0.34, -0.10)**	−0.21 (-0.35, -0.06)*	−0.09 (-0.20, 0.02)
Political orientation: missing (vs. left)	−0.24 (-0.39, -0.09)**	−0.18 (-0.31, -0.05)*	−0.17 (-0.32, -0.02)*	−0.13 (-0.25, -0.01)*
Coastal proximity: ≤1km (vs. + 20 km)		0.04 (-0.06, 0.15)	0.05 (-0.06, 0.16)	0.05 (-0.05, 0.15)
Coastal proximity: >1–5 km (vs. + 20 km)		0.08 (-0.01, 0.17)	0.09 (-0.001, 0.18)	0.10 (0.02, 0.19)*
Coastal proximity: >5–20 km (vs. + 20 km)		0.07 (-0.01, 0.14)	0.07 (-0.01, 0.14)	0.08 (0.01, 0.15)*
Coastal proximity: missing (vs. + 20 km)		0.15 (-0.17, 0.48)	0.16 (-0.17, 0.49)	0.13 (-0.17, 0.43)
Visit frequency: once a week or more (vs. less often than once a week)		0.03 (-0.05, 0.12)	0.03 (-0.06, 0.11)	−0.02 (-0.10, 0.06)
Visit frequency: missing (vs. less often than once a week)		0.05 (-0.13, 0.24)	0.05 (-0.14, 0.24)	0.05 (-0.12, 0.22)
Recreation activities: active (vs. none)		0.20 (0.12, 0.27)***	0.19 (0.12, 0.27)***	0.09 (0.02, 0.15)*
Recreation activities: passive (vs. none)		0.17 (0.09, 0.25)***	0.16 (0.08, 0.24)***	0.07 (-0.01, 0.14)
Recreation activities: watersports (vs. none)		0.005 (-0.05, 0.06)	0.01 (-0.05, 0.06)	0.01 (-0.04, 0.07)
Recreation activities: swimming (vs. none)		0.01 (-0.04, 0.07)	0.004 (-0.05, 0.06)	−0.0001 (-0.05, 0.05)
Recreation activities: eating seafood (vs. none)		0.14 (0.09, 0.19)***	0.14 (0.08, 0.19)***	0.07 (0.03, 0.12)**
Recreation activities: other (vs. none)		0.43 (0.20, 0.67)***	0.42 (0.18, 0.65)***	0.23 (0.01, 0.44)*
Recreation activities: missing (vs. none)		−0.69 (-1.17, -0.21)**	−0.68 (-1.16, -0.20)**	−0.35 (-0.79, 0.09)
Marine occupation: household member has a marine occupation (vs. no marine occupation)		−0.12 (-0.21, -0.03)**	−0.11 (-0.20, -0.03)*	−0.05 (-0.13, 0.03)
Marine occupation: missing (vs. no marine occupation)		−0.38 (-0.51, -0.24)***	−0.37 (-0.51, -0.24)***	−0.24 (-0.36, -0.11)***
Personality: openness (1 to 5)			0.05 (0.02, 0.08)**	0.02 (-0.01, 0.04)
Personality: conscientiousness (1 to 5)			0.04 (0.01, 0.07)*	0.01 (-0.02, 0.04)
Personality: extraversion (1 to 5)			0.01 (-0.02, 0.03)	0.001 (-0.03, 0.03)
Personality: agreeableness (1 to 5)			0.04 (0.01, 0.08)**	0.01 (-0.02, 0.04)
Personality: neuroticism (1 to 5)			0.02 (-0.01, 0.04)	0.01 (-0.01, 0.03)
Concern (0 to 6)				0.59 (0.57, 0.61)***
N	14,331	14,331	14,331	14,331
N (country)	15	15	15	15
AIC	52618.38	52405.40	52374.97	50018.78
χ^2		242.98***	40.43***	2358.19***
R2 (fixed)	0.02	0.03	0.04	0.19
R2 (total)	0.03	0.05	0.05	0.20

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. CI = confidence interval.

point scale, an 8.4% increase in research support for each point increase in concern. The addition of concern resulted in coastal proximity showing a significant effect, with those who lived > 1–5 km ($\beta = 0.10$, 95% CIs: 0.02, 0.19) and > 5–20 km ($\beta = 0.08$, 95% CIs: 0.01, 0.15) from the coast showing greater research support than those who lived >20 km away. Additionally, the effects found in Model 2c for gender, employment (specifically being a student), political orientation, engagement in passive marine recreation activities, marine sector occupation, openness, conscientiousness and agreeableness all became non-significant, suggesting full mediation via concern.

Further, drops in the size of associations for age, engagement in active marine recreation activities, seafood consumption and 'other' recreation activities suggested partial mediation via concern. The total variance explained by the Model 2d was 20%, an increase of 15% from Model 2c.

3.4.2. Mediation analysis

Given that we had so many predictor variables (with so many levels) and just one mediator, instead of a traditional Structural Equation Model, we ran individual mediation models for each variable of interest from Model 2d above, while controlling for all other variables. This gave us direct, indirect and total effects of each pathway of interest, through concern, accounting for all potential confounds (Table 4).

Supporting the interpretation of full mediation from Model 2d above, there were significant indirect (but not direct) effects on preferences for research into the human health impacts of marine plastic pollution via concern, for gender, political orientation (centre & right), passive coastal recreation, marine occupation, openness, conscientiousness and agreeableness. Further, and supporting partial mediation, there were significant direct and indirect effects for age, active coastal recreation and seafood consumption.

Notably, there was no significant direct or indirect effect for 'being a student' compared to those in full time employment, despite a significant total effect, and a larger estimate than other direct effects (e.g. age). This is likely due to the smaller number of respondents (N) in this category, as seen in Table S2 of the supplementary materials.

Table 4
Mediation analysis predicting research support for plastic pollution via concern.

Predictor variables	Estimate *(95% CI)*
Age (18 to 99)	
Direct effect	0.05 (0.02, 0.08)***
Indirect effect	0.09 (0.08, 0.10)***
Total effect	0.14 (0.11, 0.17)***
Gender: female (vs. male)	
Direct effect	0.04 (-0.003, 0.09)
Indirect effect	0.10 (0.08, 0.12)***
Total effect	0.15 (0.10, 0.20)***
Employment: student (vs. full-time employment)	
Direct effect	0.08 (-0.02, 0.18)
Indirect effect	0.04 (-0.01, 0.08)
Total effect	0.12 (0.003, 0.22)*
Political orientation (centre vs. left)	
Direct effect	−0.06 (-0.13, 0.01)
Indirect effect	−0.08 (-0.12, -0.04)***
Total effect	−0.14 (-0.22, -0.06)***
Political orientation (right vs. left)	
Direct effect	−0.09 (-0.20, 0.03)
Indirect effect	−0.12 (-0.18, -0.07)***
Total effect	−0.21 (-0.34, -0.09)**
Recreation activities: active (vs. none)	
Direct effect	0.09 (0.02, 0.15)*
Indirect effect	0.11 (0.08, 0.14)***
Total effect	0.19 (0.12, 0.27)***
Recreation activities: passive (vs. none)	
Direct effect	0.07 (-0.001, 0.14)
Indirect effect	0.10 (0.07, 0.13)***
Total effect	0.16 (0.09, 0.24)***
Recreation activities: eating seafood (vs. none)	
Direct effect	0.07 (0.03, 0.13)***
Indirect effect	0.06 (0.04, 0.08)***
Total effect	0.14 (0.08, 0.19)***
Marine occupation: household has a marine occupation (vs. no marine occupation)	
Direct effect	−0.05 (-0.13, 0.03)
Indirect effect	−0.06 (-0.09, -0.03)***
Total effect	−0.11 (-0.19, -0.03)**
Personality: openness (1 to 5)	
Direct effect	0.02 (-0.01, 0.05)
Indirect effect	0.03 (0.02, 0.04)***
Total effect	0.05 (0.01, 0.08)**
Personality: conscientiousness (1 to 5)	
Direct effect	0.01 (-0.02, 0.04)
Indirect effect	0.02 (0.01, 0.04)***
Total effect	0.04 (0.01, 0.07)*
Personality: agreeableness (1 to 5)	
Direct effect	0.01 (-0.02, 0.04)
Indirect effect	0.03 (0.02, 0.05)***
Total effect	0.04 (0.01, 0.07)**

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. CI = confidence interval. Results based on 1000 simulations.

4. Discussion

Marine plastic pollution is a phenomenon caused entirely by humans, that has rapidly become a global threat to marine ecosystems (Gall and Thompson, 2015; UNEP, 2016). The implications for human health and wellbeing, however, are less clear (SAPEA, 2019; WHO, 2019). The aim of the current paper was to improve our understanding of public concern about the human health impacts of marine plastic pollution, and to explore the public desire for more research into this topic, given the current debate on the potential human health impacts (SAPEA, 2019; Vethaak and Legler, 2021).

4.1. Public concern and research support

Extending previous multi-country studies that explored public concern about threats to the marine environment from a range of anthropogenic sources (Gelcich et al., 2014; Hartley et al., 2018; Potts et al., 2016), we found that European and Australian respondents were extremely concerned about the human health impacts of marine plastic pollution in particular. When compared with 15 other potential threats, including those associated with climate change (e.g. sea level rise), marine plastic pollution was the greatest public concern in 13 of the 15 countries sampled.

In addition to concern, respondents indicated that they would strongly support research funding into marine plastic pollution to better understand the health and wellbeing implications. Overall, research into marine plastic pollution was ranked second highest in terms of support for more funding, below only marine species protection. In six countries, marine plastic pollution was the research area with greatest support. This extends previous research that asked about research funding priorities for marine threats, but had not included marine plastic pollution specifically or a focus on human health (Gelcich et al., 2014).

Public concern appears to be greater than might be expected given the currently limited scientific evidence of any harm to human health, though absence of evidence of harm is not the same as evidence of no harm (SAPEA, 2019). Following the precautionary principle (Bourguignon, 2015), some recommend that a precautionary approach be taken to prevent human exposure to plastics, given the scientific uncertainty (see Leslie and Depledge, 2020; Wardman et al., 2020 for further discussion). In this sense, the public appears to be in agreement with the scientific community, and policy (e.g., the European Commission's strategy on plastics; European Commission, 2018), in being concerned enough to support more research into the issue. Reasons for this support may be a consequence of the increased media coverage and the 'Blue Planet II effect' (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection [GESAMP], 2015; SAPEA, 2019; Thompson, 2019).

4.2. Individual-level determinants

Despite research having been conducted into the individual-level determinants of other environmental threats (e.g. climate change; Poortinga et al., 2019), marine plastic pollution is distinctive. It often has an increased visibility (Syberg et al., 2018), particularly for those who interact with marine/coastal environments. However, it can also be perceived as geographically distant, especially for those who live inland. Given the ongoing debate on the health context, it is therefore important not to rely on findings from broader, more general environmental attitudes literature, and to gather topic specific data for future policy/public engagement on the issue.

Consistent with earlier research for other environmental threats, age, gender, employment status and political orientation were consistent predictors of both concern and research support (Cruz, 2017; European Commission, 2017; Hornsey et al., 2016; Zelezny et al., 2000). Those who were older, female, in education and left-wing reported greater concern about the human health impacts of marine plastic pollution and indicated greater support for research funding on the public health implications. Education level was found to be a slightly negative predictor of concern, but a significant positive predictor of research support. In short, those with a degree level educational attainment reported slightly lower levels of concern, yet greater research support. This finding is contrary to Hartley et al. (2018) who found those with a degree reported greater levels of concern for the impacts of marine litter (see also European Commission, 2020a; Gifford and Nilsson, 2014 for contrasting results regarding other issues). A possible explanation for this is that those with a degree level educational attainment are more aware that at present there is no definitive evidence surrounding the human health impacts of plastic pollution, hence they have lower concern than those without a degree. Being more educated, though, might lead to greater support for research on this specific issue but also for research in general.

It was theorized that contact with the marine environment would be associated with health-related perceptions towards marine plastic pollution, given those who have regular contact with coastal/marine environment may have increased visibility of the threat. Contrary to Milfont et al. (2014) with respect to climate change concern, and Potts et al. (2016) with respect to ocean health concern, there was no association between home proximity to the coast and concern for marine plastics and human health. Nevertheless, coastal proximity was a predictor of research support in the final model (2d), with those living within 1–20 km of the coast reporting greater support than those further away. Given the global media focus on marine plastic pollution, people across the population may be worried about the issue, regardless of where they live. However, when it comes to the specific question of research support, in which funding and resources are involved, people who are more directly impacted, i.e. those who live closer to the sea, did appear to see a greater need for more research. Consistent with Gelcich et al.'s (2014) findings with respect to concern about marine pollution in general and Hartley et al.'s (2018) findings with respect to concern about the impacts of marine litter, visiting the coast once a week or more was associated with greater concern. Thus it appears that coastal proximity and visit frequency work in combination when predicting health-related perceptions towards marine plastic pollution. People who engaged in land-based marine activities such as coastal walking, watching the view and eating seafood also reported higher levels of concern and support for research into marine plastic pollution and human health than those who did not engage in any coastal recreation activities. By contrast, those who actually entered the water e.g. watersports and swimming, did not report higher concern or support. We are puzzled by these findings given that watersport enthusiasts are often among the most active in terms of anti-marine plastic campaigns (e.g. https://www.sas.org.uk/plastic-free-communities), and clearly more work is needed to unpack this apparent contradiction.

Finally, either being in, or having a member of the household in, a marine profession (e.g. aquaculture) was associated with lower concern and less support for research. This may reflect a greater understanding and awareness that plastic pollution is not the greatest public health threat faced from the marine environment. Alternatively, these individuals may have become habituated to the threats of the marine environment, given their occupational exposure, or they may be worried that the results of such research could have adverse effects on their livelihood. Of note, given the relatively low Ns, we did not attempt to unpack marine occupation type, so are unable at this stage to see whether those employed in potentially more environmentally damaging sectors (e.g. oil and gas) are more or less concerned than those in the environmental protection sector.

Consistent with Hirsh (2010), personality traits, specifically higher levels of openness, conscientiousness and agreeableness were positively associated with greater concern and research support. Openness and agreeableness in particular have been associated with Schwartz's (1994) value of self-transcendence, which is characterised by an appreciation for nature and a care towards others (Olver and Mooradian, 2003). Therefore it is possible that those who are more open and agreeable exhibit greater concern for marine plastic pollution as they are higher in self-transcendence and exhibit a need to protect both the marine environment and human health.

In terms of research support specifically, the strongest predictor by some margin was concern. As concern for the health implications of marine plastic pollution increased, support for research understanding the health implications of marine plastic pollution also increased. Concern contributed approximately three quarters of the overall variance explained, suggesting it is a key factor in predicting research support. Mediation analyses revealed that concern fully mediated the relationship between some variables (e.g. gender) and research support. Taking gender as an example, this suggests that females express more support for research funding into the public health implications of marine plastic pollution because they are more concerned about the public health impacts. Additionally, for other variables, such as age, concern only partially mediated the relationship between research support. Characteristics such as perceived control have been associated with perceived risk of an environmental issue (psychometric paradigm, Fischhoff et al., 1978; Slovic, 1987). For example, older individuals, in addition to feeling more concerned, may feel they have less control over the health effects of marine plastic pollution, and therefore express more research support.

4.3. Implications and future research

This is the first study we are aware of to gather public perceptions of marine plastic pollution from a large relatively representative multi-country sample. Despite clear evidence that the potential human health impacts of marine plastic pollution are of greatest concern across countries, we also find that perceptions vary as a function of country of residence. These differences could be considered when creating country-specific marine policy; and may help improve the acceptability and adherence of transnational marine policies. For example, our findings suggest that individuals in some countries (e.g. the UK, Greece, France) would be more supporting of research into marine plastic pollution than other countries. The sample of the current study is however predominantly European; collecting perceptions of respondents in other geographical regions would allow us to understand better cultural and regional perception differences surrounding marine plastic pollution. It would be particularly of interest to gather perceptions of those in regions with the highest levels of plastic waste and lack of infrastructure (i.e. Asia; Jambeck et al., 2015). Similarly, studies researching perceptions of plastics have mainly gathered perceptions in coastal countries (Heidbreder et al., 2019). Given landlocked countries also contribute to the plastics cycle, understanding perceptions in more countries such as the Czech Republic would also be helpful. Additionally, single-use plastic waste on beaches has been shown to differ according to sea-basin (European Commission, 2020b), therefore, understanding how perceptions change as a function of sea basin would also be of interest.

The current results relating to individual differences may also be useful in helping public engagement exercises. Given the clear consensus surrounding the need to reduce plastic usage, there is a need to mobilise actions against plastic entering the marine environment (UNEP, 2016). Despite some individual characteristics (e.g. age) being fixed, others are more flexible (e.g. coastal visits, coastal recreation engagement). Future research could investigate if changing these more flexible characteristics, shown to be associated with concern, helps to increase concern and subsequently increases action on plastic pollution and policy support. It would also be beneficial to explore other possible predictors of attitudes towards marine plastic pollution (e.g. cultural importance of the marine environment, environmental and personal values; e.g., Schwartz, 1994). Short form measures of values (e.g. the Ten Item Value Inventory; Sandy et al., 2017) would be particularly useful in large scale surveys. Additionally, other characteristics associated with risk perception (e.g. knowledge, control and equity; Slovic et al., 1985), as well as those found to be influential in predicting climate change beliefs (e.g. affect, biospheric values and prescriptive norms; e.g., van der Linden, 2015) could be explored.

More interdisciplinary research bringing together environmental and health disciplines is also needed to understand the potential impacts of marine plastic pollution in the context of planetary and human health (Borja et al., 2020). It has been recommended that health is considered in all future marine and maritime policies (McMeel et al., 2019) as well as environmental threats considered in health policy. Whilst some policies on plastic do mention human health (European Commission, 2018), as our understanding of the health risks of marine plastic pollution develops, so too should relevant policy. With government and policy makers perceived as one of the groups with most responsibility for reducing marine litter (Hartley et al., 2018), considering human health in future plastic policy will make sure that public concerns are heard.

4.4. Potential limitations

We acknowledge several limitations with the current study. First, the survey needed to be completed within an average time of 20 min to keep within the survey company's on-line research guidelines. This resulted in various compromises about what items and phrasing to include. For example, although the support for research funding item was asked about in the wider context of public policy intervention, it did not explicitly state which types of research (e.g. natural or social science) or funding sources (e.g. public, private) respondents should consider. Although our wording may have implied that research funding is likely to be public we recognise that private research funding makes up a large proportion of total research spending in some countries, e.g. 56% in Australia (UNESCO Institute for Statistics, n.d.), and we do not know which kind of funding respondents were considering when giving their responses. Given that support for natural and social science and publicly versus privately funded research may be quite different across different socio-demographic groups, it would be interesting if future studies were able to explore this possibility more than was possible here. We note, however, that many larger scale projects are attempting to integrate the natural and social sciences to address complex environmental 'wicked problems' (for an example in the marine field see the Blue Communities Programme: https://www.blue-communities.org/Home), and that many public–private research initiatives also exist (e.g. https://www.ukri.org/councils/innovate-uk/) clouding these traditional boundaries. A slightly different issue with this item is that there was no attempt to encourage respondents to consider the potential trade-offs between different research areas, e.g. funding allocated to marine plastic pollution may reduce funding of other marine threats (e.g. marine biodiversity loss). A possible way forward in future might be to 'allocate' respondents a hypothetical budget and ask them to spread this across the fields they believe most deserving.

Although we had heterogeneous samples, representative on age, gender and region in each country, our sample was not perfectly representative so we need to be cautious when drawing conclusions for specific countries. Including concern about plastic pollution into larger, more fully representative datasets, such as the European Social Survey as has been done with climate change (Bouman et al., 2020; Poortinga et al., 2019), as well as longitudinal panels (Capstick et al., 2015), would help us draw even more robust conclusions, among a wider set of countries, and enable attitudes and concerns to be tracked over time (e.g. in response to policy initiatives or key events). For instance, the current data were collected in Australia in September 2019, however, given recent environmental crises (i.e. bushfires, pandemic), attitudes towards certain environmental issues (e.g. wildlife protection) may have changed. It should also be noted that the European and Australian data were collected in different months of 2019 (albeit both in local spring eliminating seasonal differences).

Further, our cross-sectional design restricts our ability to make causal inferences. While some of our explored predictors such as age, gender and personality can reasonably be inferred to be a causal factor in understanding concern, other more mutable behavioural factors such as types of visit (e.g. willingness to eat seafood) or employment (e.g. taking a job in the marine protection sector) may be the results of concerns, rather than a cause. Again, as noted above, exploring attitudes towards plastics in the same samples longitudinally would help address this limitation. Additionally, although the associations between some individual characteristics (e.g. age, visit frequency, personality) and concern and/or research support were statistically significant, the effects were small in absolute terms. Therefore, caution should be taken when interpreting these results, and further work is clearly needed to be able to account for the large amount of unexplained variance which still exists.

There is also a potential when collecting perceptions of environmental issues for respondents to give socially desirable answers. For example, they may believe they should show a certain level of concern or support for marine environmental issues to assimilate with perceived societal norms surrounding the environment. Nevertheless, we have focused on the relative differences between threats, and it seems unlikely that social desirability would apply more to some threats than others. Additionally, research has shown social desirability to only have a weak effect on environmental attitudes (Milfont, 2009).

5. Conclusions

The present study explored perceptions regarding the potential human health impact of marine plastic pollution across 14 European countries and Australia. Even though there is currently little scientific evidence for such health effects of plastic (e.g., SAPEA, 2019; WHO, 2019), our findings show that the European public is highly concerned about health impacts from marine plastic pollution. It is possible that the public construe the widely publicised ecological effects of marine plastic pollution as a human health effect, or that media and NGO reporting has led to an overestimation of the evidence base. Exploring these possibilities and the perceived link between environmental threats and human health would be worthwhile in future research, e.g., in cross-national public perception surveys such as the European Social Survey. This could yield important insights on novel pathways to action, as health concerns have been shown to motivate action for climate change (Bain et al., 2012; Maibach et al., 2010; Myers et al., 2012). Our findings suggest that while the respondents overall shared a high concern about marine plastic pollution, there were also some differences. Some individuals exhibit greater concern (e.g. left-wing orientated individuals, those with more open personalities), and a desire for research (e.g. those who engage in coastal walking) than others. Given that marine plastic pollution is a global challenge and all of society contributes to some degree to the plastic consumption cycle, we now need to find ways of connecting the high level of concern with ways of curbing the leakage to the environment.

Data statement

Data was collected as part of an EU project and will be made publically available after a suitable moratorium period (date still under discussion with partners). Please contact the corresponding author for data access issues in the meantime.

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Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2021.102309.

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