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Abstract

Varied categorisations of residential distance to bluespace in population health studies make comparisons difficult. Using survey data from eighteen countries, we modelled relationships between residential distance to blue spaces (coasts, lakes, and rivers), and self-reported recreational visits to these environments at least weekly, with penalised regression splines. We observed exponential declines in visit probability with increasing distance to all three environments and demonstrated the utility of derived categorisations. These categories may be broadly applicable in future research where the assumed underlying mechanism between residential distance to a blue space and a health outcome is direct recreational contact.

Keywords	proximity; water; coast; lake; river; spline
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Dr. Lewis Elliott
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Dear Professor J I Nassauer & Professor P H Verburg
Co-Editors-in-Chief
Landscape and Urban Planning

October 1st 2019

I am pleased to submit a research note entitled "Residential distance and recreational visits to coastal and inland blue spaces in eighteen countries" for consideration for publication in Landscape and Urban Planning.

Across the quantitative literature examining associations between distance to blue spaces and health outcomes, residential distance is often categorised into useful groups. While these are often purported to represent actual, direct, exposure to these environments, the categories are varied and sometimes unsubstantiated, complicating comparisons of meaningful thresholds across studies. In this study, we model relationships between residential distance and reported recreational visits to coasts, lakes, and rivers using data from representative samples of respondents from eighteen countries. Specifically, we used generalised additive mixed models to explore potential distance-decay effects between these two variables and use these to create empirically-derived residential distance categories.

We observed exponential declines in visits with increasing distance to all three blue spaces with plateaus at varying distances. We then derived and demonstrated the usefulness of 5 categories of distance to the coast (≤1km, >1km to ≤5km, >5km to ≤25km, >25km to ≤50km, and >50km), 3 categories of distance to a lake (≤1km, >1km to ≤5km, and >5km), and 3 categories of distance to a river (≤1km, >1km to ≤2.5km, and >2.5km), in subsequent generalised linear mixed models. As these categories are taken from representative samples of respondents across eighteen countries and reflect underlying recreational visit probability, we argue that they may be useful to researchers investigating associations between residential bluespace and health outcomes internationally, especially where the putative mechanism linking the two is direct, recreational contact.

We believe this article would be of interest to readers of Landscape and Urban Planning because of its international scope, and potential usefulness to scholars of health geographic, environmental epidemiological, and environmental psychological research, all of which is being increasingly well represented in the journal. While we realise we are slightly over the word limit for a Research Note, we believe the article is suitable for publication in this format as it is inherently methodological. We are happy to take editorial advice as to whether we should resubmit as a full-length article, or condense the text if necessary.

I confirm that this manuscript is not published and is not under consideration for publication elsewhere. It also does not duplicate any material already published. All authors have reviewed and approved the content of the manuscript.

We look forward to your consideration of this manuscript.

Sincerely,

Dr. Lewis Elliott

- Varied categories of residential distance to bluespace complicate study comparisons
- Modelled relationships between distance and recreational visits to blue spaces
- Used generalised additive mixed models with survey data from eighteen countries
- Exponential distance-decay relationships for coasts, lakes, and rivers were found
- We develop and demonstrate the utility of resulting general-purpose categorisations

Varied categorisations of residential distance to bluespace in population health studies make comparisons difficult. Using survey data from eighteen countries, we modelled relationships between residential distance to blue spaces (coasts, lakes, and rivers), and self-reported recreational visits to these environments at least weekly, with penalised regression splines. We observed exponential declines in visit probability with increasing distance to all three environments and demonstrated the utility of derived categorisations. These categories may be broadly applicable in future research where the assumed underlying mechanism between residential distance to a blue space and a health outcome is direct recreational contact.

Research Note: Residential distance and recreational visits to coastal and inland blue spaces in eighteen countries

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Keywords: proximity; water; coast; lake; river; spline

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1. Introduction

Investigations of natural environments and population health commonly consider associations between human health outcomes and residential distance to green spaces (e.g. playing fields, parks, woodlands; Browning and Lee, 2017). Although distance is a linear variable, research examining distance to greenspace typically categorises distance into groups (e.g. <300m; >1km etc.). This could be done to circumvent analytical or statistical complexities (e.g. highly skewed distributions); to increase policy relevance or improve communication (e.g. compatibility with the World Health Organisation's 300m urban green space indicator; Annerstedt van den Bosch et al., 2016); to address inherent non-linearity between an exposure and a health outcome (e.g. the capacity of green space to mitigate urban heat may be trivial beyond a certain distance; Shashua-Bar and Hoffman, 2000); or because the categories are purported to represent underlying human behaviour patterns which might also plausibly mediate the health outcome (e.g. typical walkable distances; Smith et al., 2010). Informed by a mixture of these, cross-national research has identified distances of 100m, 300m, 500m, and 1km as appropriate for use in a wide range of studies linking exposure to greenspace (using residential distance as a proxy) with a multitude of health outcomes (Smith et al., 2017).

Residential distance to bluespaces (e.g. coasts, rivers, lakes) may also be an important correlate of a variety of health outcomes (Gascon, Zijlema, Vert, White, & Nieuwenhuijsen, 2017), and studies have classified distance in a variety of ways. Regarding distance to the coast, UK studies have used categories of 0-1km, >1-5km, >5-20km, >20-50km, and >50km (Wheeler, White, Stahl-Timmins, & Depledge, 2012) or collapsed versions of these (Pasanen, White, Wheeler, Garrett, & Elliott, 2019; White, Alcock, Wheeler, & Depledge, 2013; White, Wheeler, Herbert, Alcock, & Depledge, 2014), to represent distinct classes of physical coastal access. Research in New Zealand has used distance bands of ≤300m, 300m-3km, 3-6km, and 6-15km (Nutsford, Pearson, Kingham, & Reitsma, 2016), and, in Australia, greater or less than 800m (Edwards, Giles-Corti, Larson, & Beesley, 2014). Research in Ireland has used quintiles within 10km of the coast (Dempsey, Devine, Gillespie, Lyons, & Nolan, 2018). Regarding water bodies and inland waterways, research in the Netherlands and France has considered the availability of blue space in 1km buffers around people's residences (de Vries et al., 2016; Perchoux, Kestens, Brondeel, & Chaix, 2015), and one study in Portugal used distances within and beyond 4km (Burkart et al., 2015). In contrast to green spaces, research investigating blue spaces faces additional complexities in that as well as occupying surface area, they are often nominally narrow linear features (e.g. rivers) which are frequently not featured on land cover maps developed from data with coarse spatial resolution. Further, given that much recreational 'access' to bluespace is to beaches, coastal paths, canal towpaths etc., the edges of bluespace are an important facet of access (Pitt, 2018; Vert et al., 2019), rather than the total surface area. Lastly, even in countries with higher availability of bluespace, people are still willing to travel considerable distances to access it (Laatikainen, Piiroinen, Lehtinen, & Kyttä, 2017). Thus distance metrics are often preferred to coverage metrics in research concerning blue spaces.

Empirically derived categorisations of distance can be useful in defining generic levels of accessibility. In the greenspace literature, "distance-decay" effects between residential distance and recreational use of green spaces have long been used as a basis for ascertaining distance categories which represent direct exposure in health geography research (Grahn & Stigsdotter, 2003). In this article we use similar distance-decay relationships across 18 countries to propose general distance categories to three prominent blue spaces – coasts, lakes, and rivers. Using international survey data collected as part of the BlueHealth project (Grellier et al., 2017), the aim of this article is to provide researchers with meaningful categories of residential distance to these three types of bluespace which are useful in defining accessibility where the putative mechanism linking distance with the health outcome is direct recreational use. Given the heterogeneity in previous distance categories used in blue space research, the use of an 18-country dataset might help define clearer thresholds that could be used across multiple countries in future which would enable greater comparability across studies.

2. Method

Methods were approved by the [ANONYMISED FOR PEER REVIEW] ethics committee (Ref: Aug16/B/099).

2.1 Sample

The BlueHealth International Survey concerns recreational use of blue spaces and its relationship with human health. It was administered online by YouGov from June 2017 to

April 2018 to panellists in 18 countries. In four seasonal stages of data collection, representative samples of 18,838 respondents were sampled from 14 European countries (Bulgaria, the Czech Republic, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, and the United Kingdom) and four other territories (Hong Kong, Canada, Australia [primarily Queensland], and the USA [state of California only]). Full methodological details are in an accompanying technical report (http://bit.ly/BIS-Technical-Report). Analyses are based on the subset of 15,216 participants (Figure 1) that provided reliable home location information, had no missing data, and that did not exhibit response biases (see technical report for details).

2.2 Exposures

Participants recorded their home location via a Google Maps application programming interface integrated in the survey. Coordinates (decimal degrees) correct to three decimal places (approximately 75m precision dependent on location) were returned and exposures assigned to these. Residential distance to the coast (n=15,216) was operationalised as the Euclidean distance from the home location to the nearest coast as defined by the highest resolution version of the Global Self-consistent Hierarchical High-resolution Geography shoreline database (Wessel & Smith, 1996). Due to a lack of globally-consistent high-resolution rivers and lakes data, the European Catchments and Rivers Network System (ECRINS) database (European Environment Agency, 2012) was used to assign Euclidean distances from the home location to the nearest lake (n=12,219) and river (or stream, canal, waterway etc.; n=12,255), separately, for the 14 European countries sampled only. ECRINS data are derived from CORINE Land Cover (CLC) data, the EU Water Framework Directive (WFD), and the EU Catchment Characterisation Model (CCM). Rivers are modelled within catchment areas and thus have no minimum width. Lakes have varying minimum mapping units depending on the original data source, spanning 25m^2 (CCM) to 500m^2 (CLC).

2.3 Outcomes

The outcome measure was the probability of respondents reporting visiting a coast, lake, or river, at least weekly within the last four weeks for recreation. Respondents were presented with the names and visual exemplars of 29 different natural environment types and asked to report how often in the last four weeks they had made a recreational visit to each using four categorical response options (not at all in the last four weeks, once or twice in the last four weeks, once a week, several times a week). Responses were dichotomised into the former and latter two response options to denote whether a participant had visited an environment at least weekly or not, consistent with thresholds identified as important in previous research (Garrett et al., 2018; White et al., 2019). We collapsed responses to: (a) eight coastal environments (pier, harbour, promenade, beach, rocky shore, cliff, lagoon, open sea) to denote 'coastal' visits, and (b) two riverside environments ('urban' river or canal [surrounded by buildings] and 'rural' river or canal [surrounded by vegetation]) to denote 'river' visits. 'Lake' visits were represented by a single 'lake' environment category.

2.4 Analysis

A distance-decay approach was employed for extracting distance categories for coasts, lakes, and rivers separately. We fitted three generalised additive mixed models with the probability of visiting a bluespace (i.e. coast, river, lake) at least weekly as the outcome variable, the respondent's country of residence as a random intercept term, and the residential distance to the corresponding bluespace as both a fixed (overall) and random (country-variant) slope term. In all three cases, specification of random slopes yielded better model fit than fixed slopes. Distance was modelled with a thin plate regression spline basis (Wood, 2003). Models were weighted to ensure estimates were representative of the countries' populations with respect to sex, age, and region of residence. These models were used to identify distances at which the distance-decay relationship changed considerably, and subsequent binomial mixed-effects models of a similar form were run, replacing the smooth function of the exposure with a new categorical variable in order to demonstrate the appropriateness of the categories. Analyses were performed in R v3.6.0 (R Core Team, 2019) using 'mgcv' (Wood, 2017) and 'lme4' (Bates, Mächler, Bolker, & Walker, 2015) packages.

3. Results

Residential distance to coast ranged from 0 to 1,192km, to lakes from 0 to 70km, and to rivers from 0 to 20km. Exposures exhibited high positive skew (Figure 2). Outliers for distance to coast included respondents residing in inland Canadian territories, Australia, and the Czech Republic. Outliers for distance to lakes were due to respondents residing in the

Greek Islands and the Puglia region of Italy. These are not analytically problematic as the probability of visiting the corresponding environments for recreation is consequently low.

The probability of visiting all three blue spaces decayed exponentially with increasing distance (Figure 3; Supplementary Figure 1) with plateaus at varying distances. For coasts, given this decline, and considering 1km has been used as a threshold in a number of studies associating distance to coast with health outcomes previously (Pasanen et al., 2019; Wheeler et al., 2012; White et al., 2013, 2014), ≤1km was chosen as the most proximal distance category. The relationship appeared to plateau around 50km – the distance at which the European Union considers a residence 'coastal' (Eurostat, 2013) – so a >50km category was also chosen. Between 1km and 50km, categories of >1km to ≤5km, >5km to ≤25km, and >25km to ≤50km were chosen as they represent an exponential geometric sequence ($\alpha_n = 5^{n-1}$) which mirrors the relationship demonstrated by the spline. An initial, most proximal, category of ≤1km was also selected for lakes and rivers based on the exponential declines demonstrated and because 1km has been used in literature linking residential distance to inland waterways with health outcomes previously (de Vries et al., 2016; Perchoux et al., 2015). For lakes, the relationship plateaued after 5km, so two further categories of >1km to ≤5km, and >5km were selected, again representing the exponential decline and maintaining consistency with those categories selected for coasts. For rivers, the relationship plateaued after 2.5km, so two further categories of >1km to ≤2.5km, and >2.5km were selected.

The utility of these categories is evidenced in the subsequent binomial mixed-effects models (Table 1). The odds of visiting the coast increased by 1.44, 2.20, 4.68, and 8.40 for each decreasing category of residential coastal distance and the odds of visiting a lake increased by 1.49 and 3.05. The categorisations did not illustrate a distance-decay effect as clearly with rivers with only those respondents living within 1km of a river significantly more likely to visit one.

4. Discussion

Studies have used a range of residential distance categories to operationalise how far someone lives from their nearest bluespace for the purposes of defining access to, likely use of, or simply general 'exposure' to, these environments. This has made comparability across studies and countries difficult. By drawing on data from 18 countries, our aim was to investigate the possibility of developing a more consistent set of distance categories that could be used to aid future comparability. Our outcome variable was whether or not an individual reported visiting the bluespace at least weekly for recreation, and thus these categories are most relevant for research investigating direct, intentional exposure (Keniger, Gaston, Irvine, & Fuller, 2013). Using a distance-decay approach, we demonstrated exponential relationships between residential distance to coasts, lakes, and rivers, and their corresponding recreational use. From this we developed distance categories which can be used in future research to define generic bluespace accessibility.

Despite using data from eighteen countries and a completely different approach to categorising distance to coasts, these categories closely resemble those used previously in the UK (Wheeler et al., 2012), and therefore bolster the author's original claim that they represent "comparative geographical accessibility and…frequency/intensity of 'exposure' to coastal environments" (p. 1199). Across different blue spaces, differences in the distance at which the relationships plateaued are likely due to a combination of their relative availability, as well as the types of visits they attract and people's motivations for visiting them (Elliott et al., 2018). As our additive models included random effects, we were able to identify countries in which distance-decay relationships are more or less prominent (Supplementary Figure 2). For example, countries bordering the Mediterranean Sea appear to have more pronounced distance-decay relationships regarding distance to coasts, suggesting that climatic or cultural factors interact with these distance-decay relationships, although a detailed discussion of these issues is beyond the scope of this short communication.

For rivers, our categorisations did not perform as well which is unsurprising given the exponential relationship we found in the initial model was neither as strong as coasts or lakes, nor as confident (wider confidence intervals were observed throughout the spectrum of distances). This perhaps owes to the narrower range of distances the respondents resided from rivers, variations in river size, or because access may be compromised by culverts, privatised land, or other features. This latter finding is consistent with previous research which found weaker associations between perceived walking distance to rivers and the frequency of their use compared to other types of blue space in two German cities (Völker et al., 2018).

A strength of the study is that our categorisations do not necessarily result in the loss of information associated with percentile categorisation, and using splines to inform the development of the categories means that we can be confident they represent the true relationship between the continuous exposure and the outcome (Lamb & White, 2015). Nonetheless, these categories cannot replace considerations of previous research or theory when deciding the distance within which a natural environment might plausibly affect a health outcome. Researchers should also be aware of the impact on statistical power that categorisations may have, and should ensure that there are appropriate sample sizes for making robust inferences when including these categories in regression models.

We are also mindful that many environment-related aspects of human health may depend on environments which are further away from home. Previous studies have demonstrated city-wide relationships between environment types and individual life satisfaction (Olsen, Nicholls, & Mitchell, 2019), and found that many people tend to visit recreational facilities further away from home for physical activity (Hillsdon, Coombes, Griew, & Jones, 2015). Nonetheless, residential exposure to natural environments remains an important determinant of health behaviours across countries (Sallis et al., 2016; Triguero-Mas et al., 2017; van den Berg et al., 2016). Furthermore, our analyses do not consider blue spaces with a surface area of less than $25m^2$ which may have affected the strength of our observed relationships. Lastly, the data used in this study were mainly from European countries, western societies, and high-income economies, and therefore may not be globally applicable.

In conclusion, we have demonstrated marked distance-decay effects concerning residential distance to bluespace and recreational use across eighteen countries. We recommend our categories for future research which attempts to associate residential distance to blue space with a health outcome, where the assumed underlying mechanism is recreational contact with those environments. The categorisation of continuous exposure metrics like these in modelling sacrifices statistical power for the sake of improving the communication of results. Researchers should be aware of this and other methodological and theoretical considerations when deciding upon appropriate distance categories.

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Figure captions

Figure 1: Given residential locations (correct to three decimal degrees) of the 15,216 respondents included in analysis. The map of Spain includes respondents resident in the autonomous city of Melilla. Respondents resident in the Canary Islands, Azores, and Madeira are not displayed.

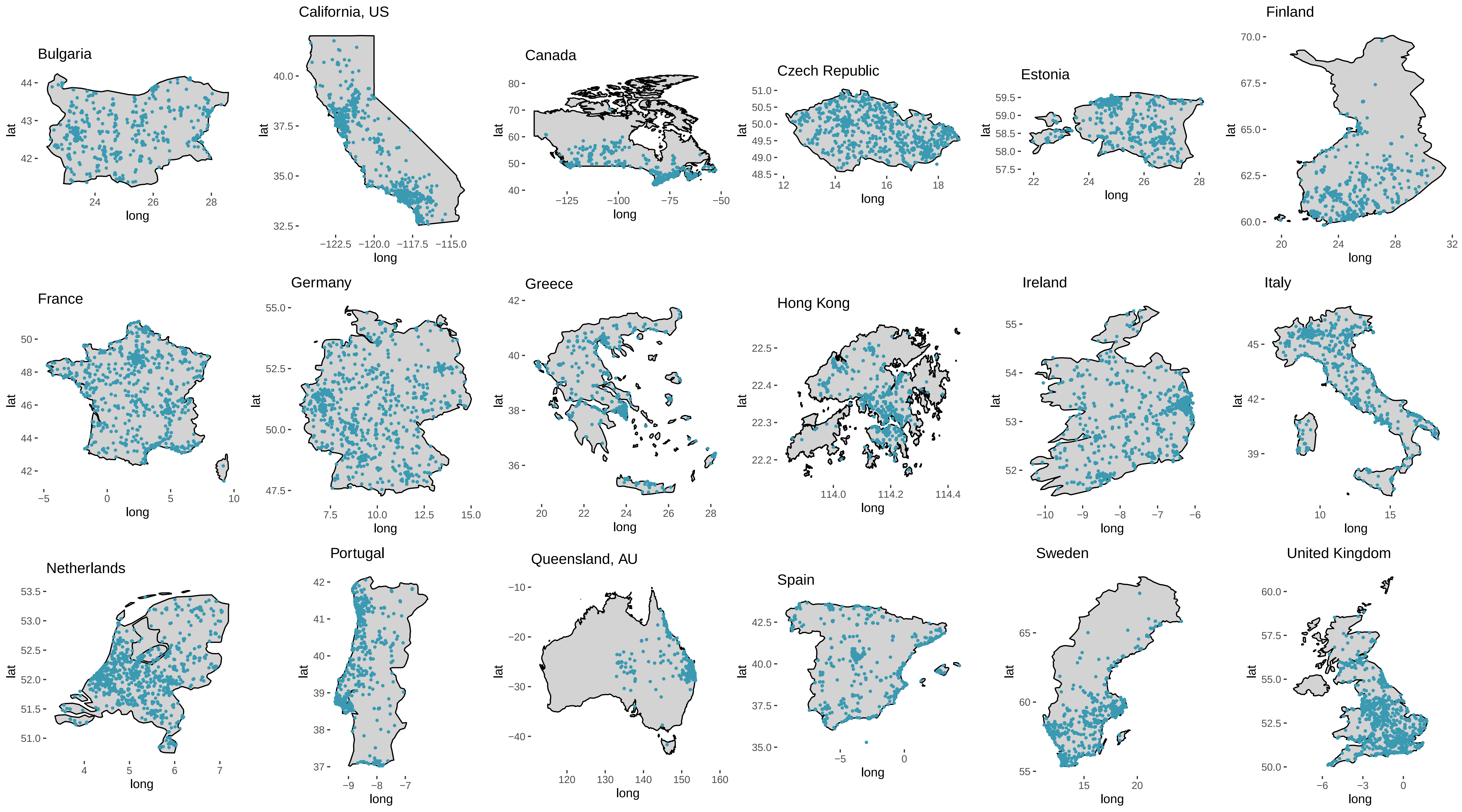
Figure 2: Smoothed distributions of residential distance to coasts, lakes, and rivers.

Figure 3: Predicted probabilities of reporting recreational visits to the coast, lakes, or rivers at least weekly in the last four weeks as a function of residential distance, derived from our generalised additive mixed models. The x-axis is truncated at distances which better display the exponential relationships. The vertical lines mark the points at which our subsequent categories start/end.

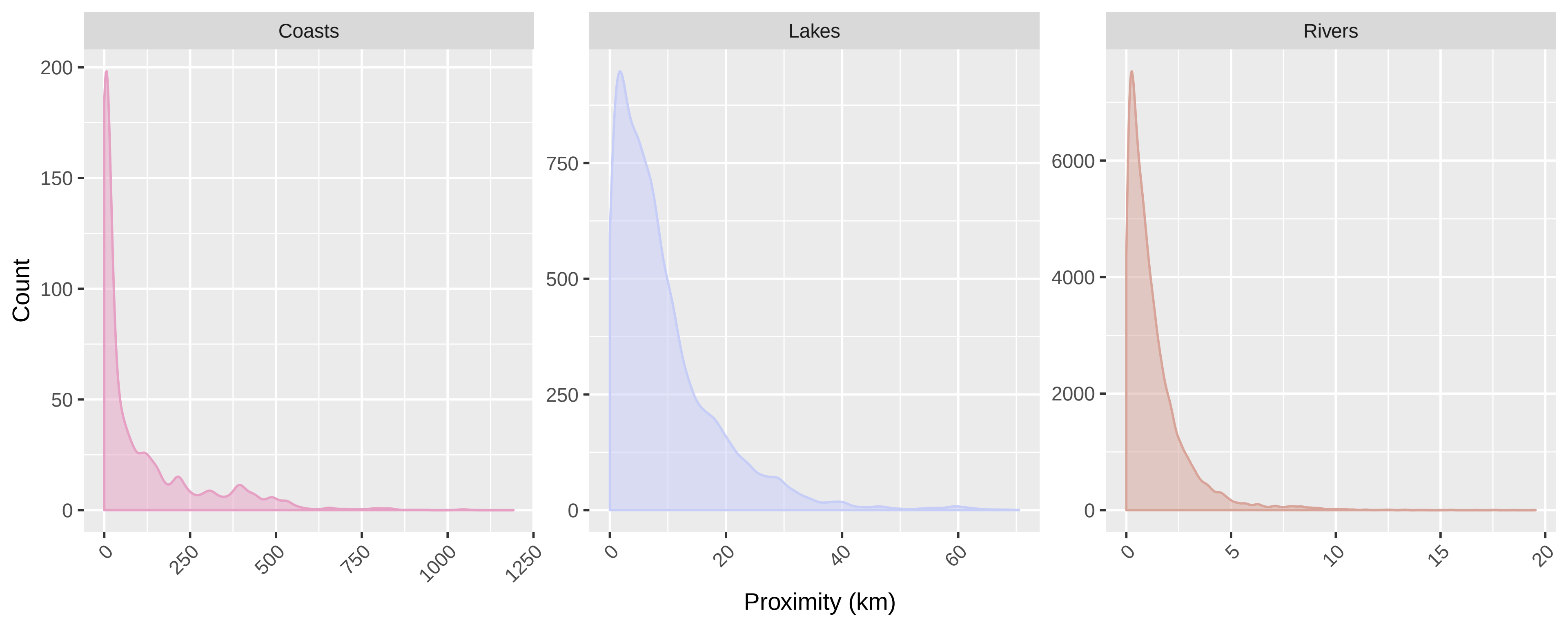
Table 1. Odds ratios and 95% confidence intervals concerning the probability of visiting each environment for recreation at least once a week in the last month as a function of distance categories

	OR	Lower confidence interval	Upper confidence interval
Coasts (n=15,216)			
Distance (>50km=ref)	/	/	/
0-1km	***8.40	5.32	13.27
>1-5km	***4.68	2.87	7.62
>5-25km	***2.20	1.55	3.10
>25-50km	*1.44	1.04	1.98
(Intercept)	***0.12	0.08	0.16
Conditional R^2	0.23		
Country-level variance	0.44		
0-1km variance	0.83		
>1-5km variance	0.97		
>5-25km variance	0.43		
>25-50km variance	0.27		
Intraclass correlation coefficient	0.11		
Lakes (n=12,219)			
Distance (>5km=ref)	/	/	/
0-1km	***3.05	2.17	4.28
>1-5km	**1.49	1.16	1.91
(Intercept)	***0.09	0.07	0.11
Conditional R^2	0.10		
Country-level variance	0.17		
0-1km variance	0.30		
>1-5km variance	0.15		
Intraclass correlation coefficient	0.07		
Rivers (n=12,255)			
Distance (>2.5km=ref)	/	/	/
0-1km	**1.56	1.19	2.03
>1-2.5km	1.05	0.85	1.31
(Intercept)	***0.20	0.15	0.28
Conditional R^2	0.06		
Country-level variance	0.28		
0-1km variance	0.16		
>1-2.5km variance	0.07		
Intraclass correlation coefficient	0.05		

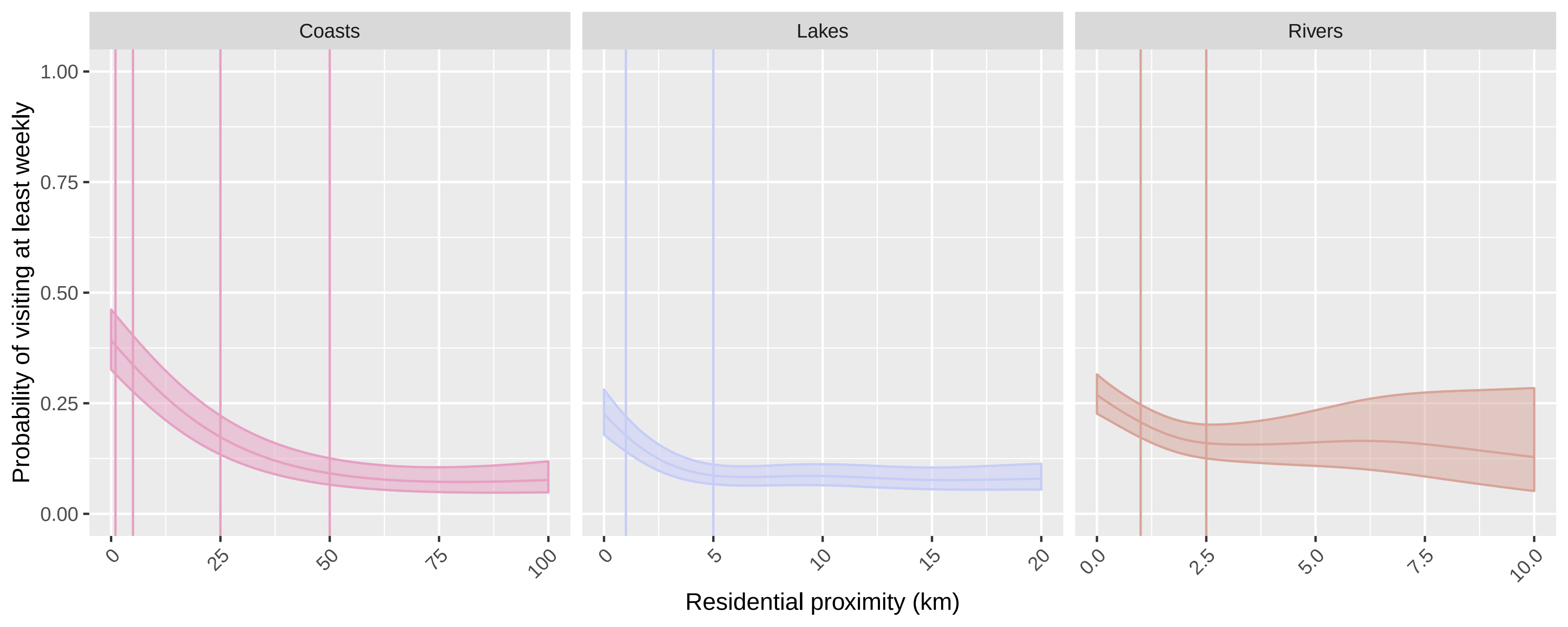
N.B Models apply survey weights and control for a random intercept of country and random slopes of distance categorisations. OR=odds ratio; ref=reference category. Conditional R^2 accounts for both fixed and random effects (Nakagawa, Johnson, & Schielzeth, 2017). *** $p<.001$, $^{**}p<.01$, $^{*}p<.05$.



Bulgaria
44
43
42
lat
24
26
28
long
California, US
40.0
37.5
35.0
32.5
lat
−122.5
−120.0
−117.5
−115.0
long
Canada
80
70
60
50
40
lat
−125
−100
−75
−50
long
Czech Republic
51.0
50.5
50.0
49.5
49.0
48.5
lat
12
14
16
18
long
Estonia
59.5
59.0
58.5
58.0
57.5
lat
22
24
26
28
long
Finland
70.0
67.5
65.0
62.5
60.0
lat
20
24
28
32
long
France
50
48
46
44
42
lat
−5
0
5
10
long
Germany
55.0
52.5
50.0
47.5
lat
7.5
10.0
12.5
15.0
long
Greece
42
40
38
36
lat
20
22
24
26
28
long
Hong Kong
22.5
22.4
22.3
22.2
lat
114.0
114.2
114.4
long
Ireland
55
54
53
52
lat
−10
−9
−8
−7
−6
long
Italy
45
42
39
lat
10
15
long
Netherlands
53.5
53.0
52.5
52.0
51.5
51.0
lat
4
5
6
7
long
Portugal
42
41
40
39
38
37
lat
−9
−8
−7
long
Queensland, AU
−10
−20
−30
−40
lat
120
130
140
150
160
long
Spain
42.5
40.0
37.5
35.0
lat
−5
0
long
Sweden
65
60
55
lat
15
20
long
United Kingdom
60.0
57.5
55.0
52.5
50.0
lat
−6
−3
0
long



Coasts
Lakes
Rivers
Count
Proximity (km)
200
150
100
50
0
250
500
750
1000
1250
750
500
250
0
20
40
60
6000
4000
2000
0
5
10
15
20

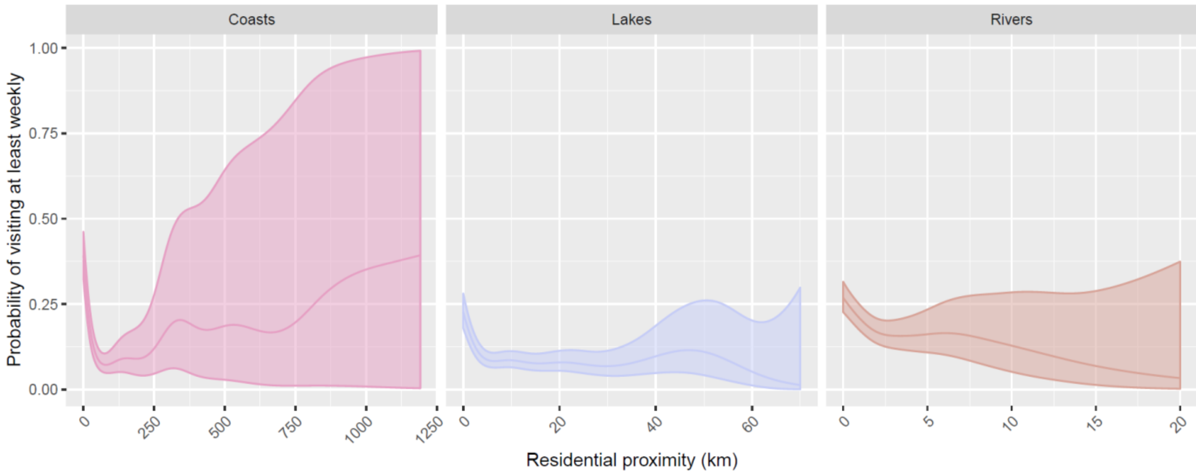

Coasts
Lakes
Rivers
Probability of visiting at least weekly
1.00
0.75
0.50
0.25
0.00
0
25
50
75
100
0
5
10
15
20
0.0
2.5
5.0
7.5
10.0
Residential proximity (km)

Supplementary Table 1. Results of initial generalised additive mixed models predicting the probability of visiting each environment for recreation at least weekly in the last four weeks from an unknown smooth function of residential distance to each environment (modelled with thin-plate regression splines).

	Effective degrees of freedom	Chi-squared test
Coasts		
Distance	8.58	***392.98
Tjur's R^2	0.16	
Country-level variance	0.35	
Distance variance	0.00	
Lakes		
Distance	7.01	***134.75
Tjur's R^2	0.04	
Country-level variance	0.23	
Distance variance	0.00	
Rivers		
Distance	4.24	***43.66
Tjur's R^2	0.04	
Country-level variance	0.16	
Distance variance	0.02	

N.B Models apply survey weights and control for a random intercept of country and random slopes of residential distance to each environment. Tjur's R^2 represents the difference between the averages of fitted values for successes (i.e. visited in the last week) and failures (i.e. did not visit in the last week), respectively (Tjur, T., 2009. Coefficients of Determination in Logistic Regression Models—A New Proposal: The Coefficient of Discrimination. The American Statistician 63, 366–372. https://doi.org/10.1198/tast.2009.08210). *** p<.001

Supplementary Figure 1. Predicted probabilities of visiting the coast, lakes, or rivers at least weekly in the last four weeks as a function of residential distance, derived from our generalised additive mixed models. These are the same relationships that are depicted in Figure 3 of the main manuscript, but including the entire spectrum of distances in the data.



Supplementary Figure 2. Country-level distance-decay effects derived from the random effect components of our generalised additive mixed models.