FACULTY OF MEDICINE AND HEALTH SCIENCES

FACULTY OF POLITICAL AND SOCIAL SCIENCES

THE COAST AND HUMAN HEALTH

Alexander Hooyberg

2024

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An analysis of psychological, physiological, and social phenomena

Alexander Hooyberg

GHENT UNIVERSITY

Doctoral thesis
submitted to fulfil the requirements for the degree of
"Doctor of Health Sciences and of Sociology"

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To Maxim Hooyberg (1993-2009),
my brother whose innate rationalism will always be my biggest source of inspiration.

Preface

The job of a doctoral researcher is to deliver the science that advances society beyond the most pressing challenges. The Flanders Marine Institute (VLIZ) in Ostend, Belgium, has more than 20 years of experience with scoping the marine research landscape in order to provide support for marine data management, expeditions at sea, spreading ocean literacy, and ensuring innovative valorizations. It is strategically housed amongst the Secretariat of the European Marine Board, the UNESCO Intergovernmental Oceanographic Commission project office for International Oceanographic Data and Information Exchange (IOC IODE), the European marine observation and data network (EMODnet), and the local policy organ Het Streekhuis Kust of the Province West-Flanders. Given its history and location, VLIZ had developed a perspective that enables to solve challenges at interfaces of the public-policy-science-industry quadruple helix. Because of its unique positioning, it recognized that the most pressing challenges about the relationship between the ocean and human's activities were not being investigated sufficiently. Therefore, VLIZ started a Research Department in 2017. Quickly after, it put Ocean and Human Health research on the agenda, which would eventually form one of the three core umbrella divisions anno 2024, next to investigating climate change and marine observations.

This doctorate and one other were enrolled on the topic 'The Ocean and Human Health' under supervision of the division's leader dr. ir. Gert Everaert. For this doctoral research, three additional supervisors from Ghent University (UGent) provided the required scientific and strategic insights. Prof. dr. Stefaan De Henauw of the Department of Public Health and Primary Care ensured that the research was clinically relevant and applicable. Prof. dr. Henk Roose from the Department of Sociology guaranteed that the research was put in perspective of social drivers of behavior and interpersonal differences. Dr. Nathalie Michels from the Department of Developmental, Personality and Social Psychology contributed by translating her expertise on the effects of green nature on different psycho-physiological biomarkers of stress to the setting of the coast. The supervisors from UGent nicely complemented the background of dr. ir. Gert Everaert in ecotoxicology and bio-engineering. As such, the interdisciplinary interaction between VLIZ and UGent was secure, mutually beneficial, respectful, and fruitful. Due to the innovative nature of the work presented in this dissertation, additional expertise was drawn in of prof. dr. Robert Malina and dr. Ilias Mokas of the Centre for Environmental Sciences (University of Hasselt), who shared their raw ideas from an environmental economics perspective. Also, prof. dr. Marie-Anne Vanderhasselt and dr. Jens Allaert from the Ghent Experimental Psychiatry Lab critically examined some of our study designs and choices (of Chapter IV and Chapter III, respectively). Internationally, prof. dr. Mathew White of the Cognitive Science Hub (University of Vienna) and dr. Lewis Elliott of the European Centre for Environment and Human health (University of Exeter) contributed by this work by helping to frame it within the international research landscape.

As the doctoral researcher, my challenge was to execute the research while weighing everyone's input with my own perspectives on the case. At onset, I only had the raw and inexperienced conceptions that I inherited from my master of biology in global change ecology. Throughout the PhD, my colleagues, friends, and other non-experts have repeatedly asked me how my background fitted in the topic. Although this was not immediately clear to myself in the beginning as well, later, I realized that my background was perfect for placing the insights from psychological and social sciences in an environmental and evolutionary perspective. In any case, I hope I made the most adequate decisions on every nexus throughout the doctoral research.

What at the beginning seemed to be a complex web of interactions between different exposures, mechanisms, and outcomes quickly distilled in four sequential focal points. First, actual evidence was needed that the coast provides benefits for health. Second, insights were needed about the extent to which different elements of the environment influences the health outcomes. Third, the range of outcomes had to be inspected to obtain evidence that was as objective and adequate as possible. Fourth, the social patterns of distinction had to be surfaced to lay the foundations for individual-specific interpretations when all results were put together. With these four focal points, the idea was to lay the basis for future in-depth analyses. In a way, this dissertation can be considered as the first coherent exploration of the most critical phenomena in the relationship between exposure to the coast and human health. I hope that this dissertation may aid and accelerate future research about the ocean and human health.

My personal ambition for pursuing this doctorate is multifold. My kin know me as a kind son, brother, husband, and father with a deep and true love for the beauty, harshness, and causality in nature. A lot of my motivation comes from several positive and negative events in my personal life. Almost unconsciously, these life-events have made me want to provide my family with the necessary stability and to be an example for my peers and the next generation. That motivation was further strengthened by my ever-growing enthusiasm for the power of science and technology, ecology, evolution, biodiversity, and ecosystem services. Apparently, my personal background and professional interest resulted in a mindset characterized by a drive to always keep learning, an appreciation of human error, and a hope for a better future. As a result, I developed a commitment to become an independent researcher who feels at home in all the disciplines that are needed to investigate the issue. Let this dissertation represent the result of my motivation, mindset, and the support from everyone involved.

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Acknowledgements

Research requires teamwork. The studies presented within this PhD would not have reached the same quality without the involvement of my supervisors. I always felt truly privileged to have prof. dr. ir. Gert Everaert as my direct supervisor at VLIZ. From the beginning, Gert taught me the importance of patience, transparency, planning, professional relationships, and thinking out study designs thoroughly. At the start of this PhD, the OHH research at VLIZ had yet to be operationalized. Gert ensured that I could follow a clear vision and align this PhD to have it fit within the inner and outer departmental research landscape. Being always there, Gert was not only a excellent leader, but also a kind tutor, manager, and coach. Gert brought me in contact with my academic promotors, who gave me reliable access to expertise from health sciences and sociology. For the most experienced one of the three, prof. dr. Stefaan De Henauw, the title 'administrative promotor' seems rather unjustified. That is because he not only nicely fulfilled his role to help me manage the necessary paperwork – as the title would suggest –, but he was also actively and exquisitely involved with the development and interpretations of the studies and with kindly pointing me to helpful resources and opportunities. One of his post-docs at the time, dr. Nathalie Michels, devoted even more time to supporting me with this PhD, and she quickly became my go-to person for daily questions about matters of nature and health. Most often, she would answer my call with more questions, which might have felt a bit annoying at the beginning, but was exactly what I needed. As such, she taught me to find my silent inner voice and helped developing me to think three steps ahead. Last, but definitely not least, prof. dr. Henk Roose introduced valuable sociological insights and methods to our team meetings. Although sociology was completely new to me, the way he explained them allowed me to easily integrate them with the health sciences and with my biological background. He even made me so enthusiastic about it that now I cannot see the world anymore in a similar way as I did before, and that even my mother who knows me so well is astonished every time I talk about sociological mechanisms in every-day life. To my supervisors, you know that there are much more things that you did for me that I did not mention here, but know that I will always foster all the lessons you taught me and the skills you helped me to develop. Thank you for this PhD not being the end of my academic career, but instead the best-possible start I could wish for to develop something flourishing in or out of academics.

One could think that a doctoral researcher who has such an excellent team of supervisors would need no one else to do the job. I agree. However, my mindset of 'the more, the better' led me in a couple months to reaching out to additional experts in related fields that were also keen on sharing their knowledge to further strengthen the quality and interdisciplinarity of this PhD. First joining my team were prof. dr. Mathew White, dr. Lewis Elliott, and their teams from the University of Exeter and the European Centre for Environment and Human health. Their findings form the backbone of the cited literature in this PhD, because they

are among the top experts and the forerunners in this field internationally. Every time I interacted with each of them happened in a kind, supportive, and often fun manner, and I was always left with crucial inspiration for my next studies. Mat and Lewis, you are my role models, and I sincerely hope that we can further valorize our relationship for many years in the future. Next joining our team were prof. dr. Robert Malina and dr. Ilias Mokas from the Centre for Environmental Sciences (Hasselt University). As experts in environmental economics and the use of virtual reality, they were highly valuable to help me design the virtual-reality experiment (Chapter IV) with the right equipment and in supporting me to do an initial attempt to translate the effects of the coast on human health to monetary values. I am eager to strengthen our collaboration in the near future when the effects of the coast become more accurately quantified and when economic valuations of these effects become truly imperative. The last experts that joined my team are prof. dr. Marie-Anne Vanderhasselt and dr. Jens Allaert from the Ghent Experimental Psychiatry Lab. When it comes to measuring and understanding the psycho-physiology of stress, it seems fair to say that they are amongst Europe’s finest researchers. They guided me through my ever-first experiments involving human participants, and taught me to design my studies as such that I always have maximal control about the state my participants are in and that I can measure as much psychological and physiological variables as possible. Their feedback and the courses they organized have fueled my self-confidence considerably. To my expert committee, thank you for your enthusiastic involvement and expert-level contributions to my PhD. Going beyond my promotors must not have been easy, but you succeeded by further improving the quality of this PhD doubtlessly and significantly.

The involvement of my promotors and expert committee resulted in a rapid and ongoing learning curve for me. This rapid growth had to be counterbalanced with moments of ease, stability, and freedom in my private life. My wife, Lies De Vogelaere, perfectly understood these needs for me and supported me in various ways. Not only did she listen to me when I needed to ventilate about the developments at work over and over again, she also left me alone or brought me the necessary distractions when I needed it. During my PhD, we went from living with our parents, to making ourselves a new place to call home, to formalizing our bond with each other on our wedding, and to raising our two beautiful daughters. Lies, without you and all of your love by my side, I would not have mentally survived this PhD, I would not have been able to stay true to myself, and I would not have had the strength to go beyond what was necessary. You have always been vital to my good health and well-being. Besides my wife, my friends and wider family were also always there for me. Although our conversions about my PhD were usually limited to me giving an update, I knew that they always supported me whatever choices I made. Particularly, my mom, Charlotte Van de Moortel, and dad, Hans Hooyberg, deserve a special gratitude for all their explicit mental support and the educational, material, financial, and, other types of support I received over the years. I am very proud that I may carry their unique mix of genes, that their nurturing has fueled my capacities to the levels necessary to start the PhD. I also want to give special thanks to my friend and physiotherapist Sarah Defour, who shared her valuable insights about the psycho-bio-mechanics of my body. Sarah, know that I am extremely grateful for how you made me experience true biomechanical relaxation and

taught me how to achieve that. This helped me to execute my job more efficiently and to understand the muscularly effects of stress.

In one of the last stages of this project, it was up to the seven members of the examination committee to review the scientific quality, written and graphical presentation, level of interdisciplinarity, strengths, and weaknesses of the dissertation. Their raw and unbiased feedback was framed in a remarkably constructive manner and helped me to significantly improve the dissertation before publication and printing. To the chair, prof. dr. Patrick Calders, and to the referees prof. dr. Piet Bracke, prof. dr. Colin Janssen, prof. dr. Jan Mees, prof. dr. Jan Mees, prof. dr. Hans Keune, dr. Karen Van Campenhout, and prof. dr. Benedict Wheeler, thank you for having accepted to evaluate my thesis, to have critically examined the thesis by its strengths and weaknesses, and by having pinpointed the missing pieces of the puzzle.

As a last note of gratitude, I want to thank all those involved in acquiring the funding for this work: prof. dr. ir. Gert Everaert, dr. ir. Michiel Vandegehuchte, prof. dr. Jan Mees, the general management of VLIZ, the Department Economy, Science and Innovation of the Flemish government, and the province West Flanders. I also want to thank my colleague-PhD-researchers of VLIZ with who I could ventilate and discuss about PhD-related topics, and everyone else who made me enjoy working at the office more than working from home. I want to give a last note of gratitude to everyone who attended my presentations, who listened to me when talking about my work and asked questions about it, who shared their insights on my work, who organized or tutored me courses, and who gave me some of their time for whatever reason. You are also part of my team.

Research requires teamwork, and I am extremely grateful to have an excelling team to have my back.

Summary

Humans' intense use of the worlds' resources has led to a pressing need for innovative solutions that foster more sustainable interactions with the environment, particularly with regard to coastal tourism (Chapter I). In this context, research on 'Ocean and Human Health' means to increase the evidence and understanding about the effects of exposure to the coast on human health (H2020 SOPHIE Consortium, 2020). The framework of White et al. (2020) maps how exposure to the coast (i.e., proximity to the coast, intentional, incidental, and indirect) influences health via restorative (e.g., stress-reduction), instorative (e.g., promotion of physical activity and social interactions), and mitigative (e.g., less air pollution) pathways, and how situational and individual factors may impact these pathways (White et al., 2020). Although many narratives and isolated studies about these pathways have pointed to the potential benefits of the coast for human health, there is still a major knowledge void about the actual effects of exposure to the coast on humans' psychological and physiological states and the social structuring of these effects.

This doctoral research aimed to increase the evidence and our understanding about the effects of the coast on human health in Belgium. Four empirical studies and a data descriptor were completed to achieve this. First, an epidemiological study used data from the Belgian Health Interview Survey (N = 60,939, 1997-2013) to find that Belgian citizens living at less than 5 kilometers of the coast report a better general health than populations living more inland (Chapter II; Hooyberg et al., 2020). These analyses also revealed that none of the four hypothesized mechanisms (i.e., mental health, physical activity, social interactions, and air pollution) are responsible for this relationship, potentially because the visit frequency was not considered. Second, a picture-rating study was performed with students (N = 102, 18-30y, 83% female), which highlighted that the 'naturalness' of a coastal environment determines its potential to reduce stress and restore attention deficits (Chapter III; Hooyberg, Michels, et al., 2022). Third, a virtual reality experiment on 164 participants (18-65y, 68% female) demonstrated that beaches caused lower breathing rates than urban environments and lower sympathetic arousal than green environments (Chapter IV; Hooyberg, Michels, et al., 2023). This study also showed that participants who had a moderate stress in the past week would be able to reduce perceived stress and negative mood better from exposure to beaches than to green or urban environments. Next, an online survey gathered data about the frequency and characteristics of the visits to the Belgian coast in 2022 (e.g., season of visiting, activities performed, social company, gained experiences) and diverse geo-demographic, socio-economic, health traits of a representative sample of the Flemish population (N = 1939; Chapter V; data at https://doi.org/https://doi.org/10.14284/625; Hooyberg, Roose, et al., 2023). The descriptor of the openly available data explains its content and quality and how it allows to investigate the social structuring of coastal visits and matters of coastal epidemiology and accessibility, health and psycho-physical experiences, social relations, and issues of time, season, and weather. Last, an analysis was done on the respondents to the survey who reported to

have visited the coast in the previous year (N = 1302; Chapter VI). By analyzing their coastal leisure activities and social company at the coast, four dimensions were revealed that structured the variation: a dimension of engagement vs. disengagement, a dimension of nature-based vs. urban-based activities, a dimension of activities with family vs. with friends, a club, or alone, and a dimension of a social vs. exploring purpose. Five clusters of individuals who had a relatively similar coastal visit profile were also identified : 'generalists' who have a relatively larger share of middle-aged, higher educated adults with partners and kids; 'engagers in nature' who seem to have the coast embedded in their lifestyle and mainly do activities in natural environments at the coast; 'engagers in the city' who are typically young (18-29y) or old (>=65y), physically active, higher educated, and frequent visitors of the coast that do not visit the coast with family; 'disengagers in nature' who are more likely to be young, socially isolated individuals who explore nature at the coast alone; and 'disengagers in the city' who are more likely to be retired (>= 65y) off-season visitors that most often eat out and dwell in the coastal cities with a partner.

The results presented in this dissertation increased the body of evidence and our understanding about the effects of coastal environments on human health by providing evidence for the conceptualized pathways in the framework of White et al. (2020). More specifically, it expanded the geographical scope of evidence, described the spatial variation in psychological restorativeness at the coast, revealed the psychophysiological effects of beaches, and charted the social structuring of coastal visits and experiences (Chapter VII). However, the knowledge gap remains large. Future research can focus on how different doses of the coast (e.g., different frequencies, durations, and activities) impact different health outcomes, and how the coast may help to strengthen people's bio-psycho-social resilience. Future research should investigate how the effects of the coast can be implemented in health care to combat poor mental health (e.g., via 'blue social prescribing'), what the economy gains from the effects of the coast on health, and how ocean literacy can nurture a culture of care for a more sustainable coastal tourism. The future of the research topic can draw inspiration from 'the specific approach to health' to set the topic's boundaries, to update the framework of White et al. (2020), and to communicate clearly and unambiguously about the topic and the underlying motivation to its various stakeholders. All in all, the research within this dissertation demonstrated the existence of important psychological, physiological, and social phenomena at the Belgian coast.

Summary in Dutch (*Samenvatting*)

De grondstoffen van de Aarde worden intensief gebruikt door de mens. Dit heeft geleid tot een hoge nood aan innovatieve oplossingen die een duurzamere interactie met onze omgeving mogelijk maken, vooral met betrekking tot kusttoerisme (Chapter I). Met deze nood in het achterhoofd wil het onderzoek naar 'de gezondheid van de mens en oceaan' beter begrijpen hoe blootstelling aan de kust de menselijke gezondheid beïnvloedt (H2020 SOPHIE Consortium, 2020). Er is een conceptueel kader van White et al. (2020) biedt houvast over hoe verschillende soorten blootstelling aan de kust (bv. wonen nabij de kust of door opzettelijk, incidenteel, en indirect contact) de gezondheid van mensen kunnen beïnvloeden via mechanismen van herstellende aard (bv. bevordering van herstel na stress), bevorderende aard (bv. aanzetten tot fysieke activiteit en sociaal contact), en beschermende aard (bv. minder luchtvervuiling), en hoe bepaalde situaties of individuele eigenschappen deze mechanismen verder kunnen beïnvloeden. Hoewel er veel verhalen en individuele studies zijn die het potentieel van de kust voor de menselijke gezondheid aantonen, bestaat er nog steeds weinig evidentie en duidelijkheid over de effecten van blootstelling aan de kust op de psychologische en fysiologische gezondheidsstatus en de sociale structurering van deze effecten.

Dit doctoraatsonderzoek doelde op bewijs verzamelen over de effecten van de kust op de menselijke gezondheid in België en de interacties tussen blootstelling aan de kust en gezondheid beter begrijpen. Om dit te bereiken, werden vier empirische onderzoeken voltooid en werd een dataset openlijk beschikbaar gemaakt en beschreven. Een eerste epidemiologisch onderzoek analyseerde de gegevens uit de Belgische Gezondheidsenquête (N = 60.939, 1997-2013). Zo kon het vaststellen dat Belgen die op minder dan 5 kilometer van de kust wonen een betere algemene gezondheid aangeven dan Belgen die meer landinwaarts wonen (Chapter II; Hooyberg et al., 2020). Uit deze analyses bleek ook dat geen van de vier veronderstelde mechanismen, namelijk een verlaagde hoeveelheid mentale stress, fysieke activiteit, en sociale interacties en minder luchtvervuiling, het effect op de zelf-gerapporteerde algemene gezondheid kon verklaren. Dit is te verklaren door dat er geen rekening gehouden werd met de verschillende frequentie waarbij mensen die op verschillende afstanden wonen van de kust de kust bezoeken. In een tweede studie beoordeelden studenten (N = 102, 18-30 jaar, 83% vrouwen) verschillende omgevingen aan de kust via foto's. Hieruit bleek dat de natuurlijkheid van een kustomgeving de mate van stress- en aandacht-herstel bepaalt (Chapter III; Hooyberg, Michels, et al., 2022). De derde studie was een virtual reality experiment met vragenlijsten en fysiologische metingen op 164 deelnemers (18-65 jaar, 68% vrouwen; Hoofdstuk III). Deze studie toonde aan dat stranden een lagere ademhalingssnelheid veroorzaken dan stedelijke omgevingen en een lagere sympathische activiteit veroorzaken dan groene omgevingen (Chapter IV; Hooyberg, Michels, et al., 2023). Uit dit onderzoek bleek ook dat deelnemers die de afgelopen week matige stress hadden hun gevoel van stress en negatief gemoed beter kunnen verlagen door blootstelling

aan stranden dan aan groene of stedelijke omgevingen. Vervolgens verzamelde een online-enquête gegevens over de frequentie en kenmerken van de bezoeken aan de Belgische kust in 2022 (bv. seizoen van bezoek, uitgevoerde activiteiten, sociaal gezelschap, opgedane ervaringen) en diverse geo-demografische, sociaaleconomische, en gezondheidskenmerken van een representatieve steekproef van de Vlaamse bevolking (N = 1939; Chapter V; data beschikbaar via https://doi.org/https://doi.org/10.14284/625; Hooyberg, Roose, et al., 2023). De inhoud en kwaliteit van de data werden uiteengezet. De gegevens kunnen gebruikt worden om de sociale structurering van kustbezoeken te onderzoeken, alsook relaties met betrekking tot kustepidemiologie en toegankelijkheid, gezondheid en psychofysische ervaringen, sociale relaties en tijd, de seizoenen en het weer. Tenslotte werden de antwoorden nader geanalyseerd van de respondenten die aangaven het afgelopen jaar de kust te hebben bezocht (N = 1302; Chapter VI). De variatie in hun vrijetijdsactiviteiten aan de kust en hun sociale gezelschap bleken gestructureerd te kunnen worden door middel van vier dimensies: een dimensie die activiteiten structureert op basis van hoe vaak ze gedaan worden, een dimensie die activiteiten in de natuurlijke versus in stedelijke omgevingen onderscheidt, een dimensie die activiteiten met familie versus met vrienden, een club, of alleen onderscheidt, en een dimensie die kustbezoeken met een sociaal versus verkennend doel onderscheidt. Er werden ook vijf clusters van individuen geïdentificeerd met een vergelijkbaar kustbezoekersprofiel: 'generalisten' met een relatief groter aandeel hoger opgeleide volwassenen van middelbare leeftijd met partners en kinderen; 'frequente natuurbezoekers' die de kust in hun levensstijl lijken te hebben verankerd en vooral activiteiten ondernemen in natuurlijke omgevingen aan de kust; 'frequente stadsbezoekers' die doorgaans jong (18-29 jaar) of oud (>=65 jaar), fysiek actief, hoger opgeleid en frequente bezoekers van de kust die de kust niet met familie bezoeken; 'occasionele natuurbezoekers', die eerder jonge, sociaal geïsoleerde individuen zijn die alleen de natuur aan de kust verkennen; en 'occasionele stadsbezoekers', die typisch gepensioneerd zijn (>= 65 jaar) en de kust buiten het seizoen bezoeken om de stad te verkennen of om uit te gaan eten met een partner.

De resultaten van het onderzoek in dit proefschrift hebben bijgedragen tot de internationale wetenschappelijke literatuur door de geografische reikwijdte van de evidentie naar België uit te breiden, de ruimtelijke variatie in psychologisch herstelvermogen aan de kust te beschrijven, de psychofysiologische effecten van stranden aan te tonen, en de sociale structurering van de kust in kaart te brengen (Chapter VII). Op die manier heeft het bijkomende bewijzen en inzichten geleverd over de effecten van de kust op menselijkheid gezondheid in het conceptueel kader van White et al. (2020). Echter, het kennishiaat blijft groot. Toekomstig onderzoek moet zich vooral richten op de manier waarop verschillende doses van blootstelling aan de kust (bv. verschillende frequenties, duurtijd, activiteiten) verschillende aspecten van gezondheid beïnvloeden, en hoe de kust kan helpen de bio-psycho-sociale veerkracht te versterken. Toekomstig onderzoek kan nader onderzoeken hoe de effecten van de kust kunnen worden geïmplementeerd in de gezondheidszorg om mentale problemen te helpen bestrijden (bv. via de kust op voorschrift), wat de economische gevolgen zijn van de effecten van de kust op gezondheid, en hoe oceaangeletterdheid een cultuur kan creëren voor het kusttoerisme waarbij zowel zorggedragen wordt voor de mens als voor de oceaan. De toekomst van het onderzoek kan inspiratie putten uit ‘de specifieke benadering van gezondheid’ (geconceptualiseerd in Chapter I.2) om het onderzoeksonderwerp duidelijk af te bakenen, om het kader van White et al. (2020) te herzien, en om duidelijk en ondubbelzinnig te communiceren over het onderwerp en de onderliggende motivatie naar de verschillende stakeholders. Concluderend kunnen we stellen dat het onderzoek in dit proefschrift belangrijke psychologische, fysiologische, en sociale fenomenen heeft aangetoond.

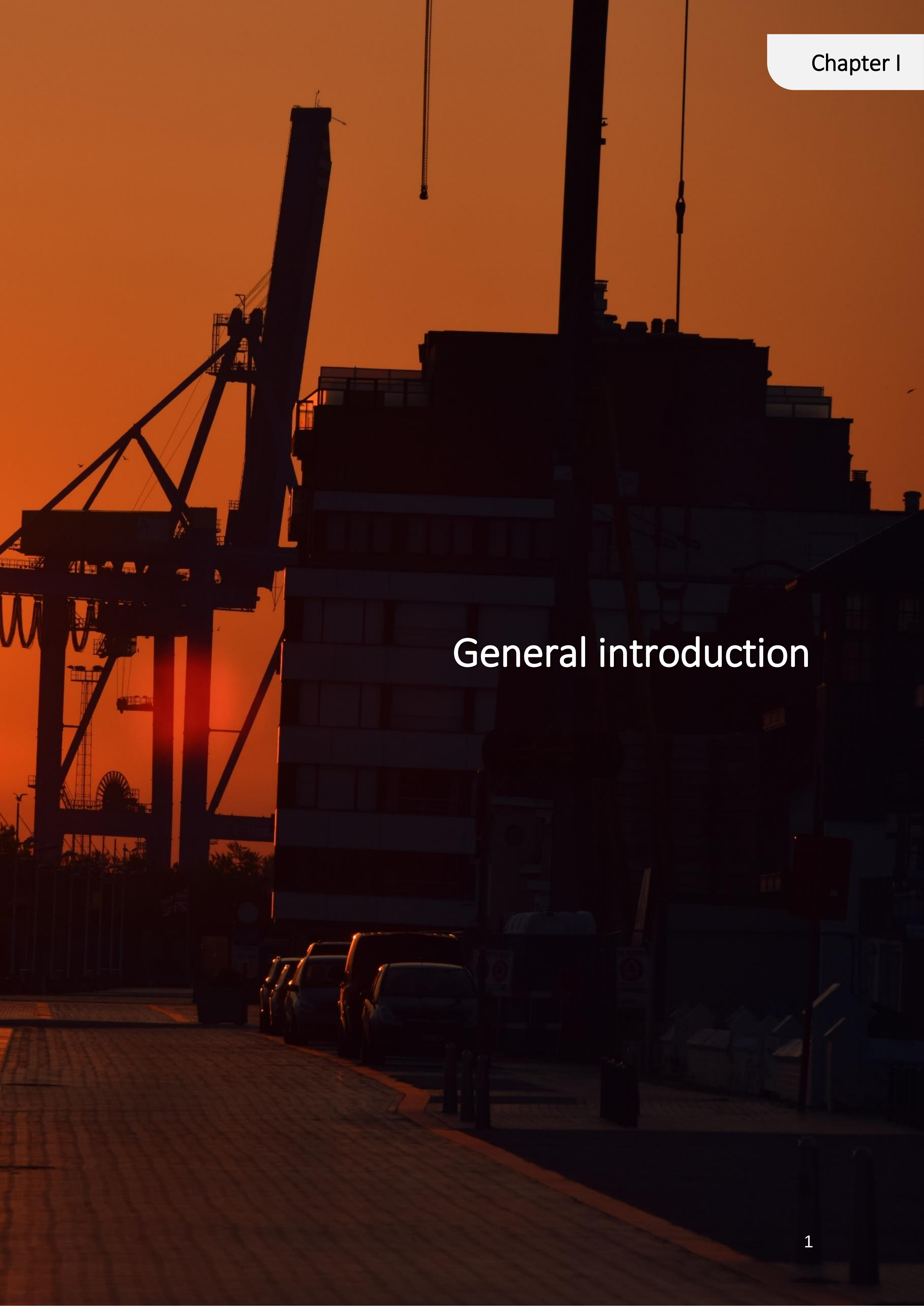
List of abbreviations

AHC	Ascending Hierarchical Clustering
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
ART	Attention Restoration Theory
B	Unstandardized model coefficient
BAT	Burnout Assessment Tool
BH	Benjamini-Hochberg
BMI	Body Mass index
CI	Confidence Interval
DASS	Depression, Anxiety, and Stress Scale
df	Degrees of freedom
ECG	Electrocardiogram
EM Mean	Estimated Marginal Mean
ESRI	Environmental Systems Research Institute
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
Figure S	Supplementary figure
fps	Frames per second
GDP	Gross Domestic Product
GHQ-12	General Health Questionnaire
GIS	Geographical Information System
GLMM	General Linear Mixed Model
H2020	Horizon 2020
HF-HRV	High-Frequency Heart Rate Variability
HIS	Health Interview Survey
HPA axis	Hypothalamic-pituitary-adrenal axis
Hz	Hertz
ID	Individual characteristics
IPAQ	International Physical Activity Questionnaire
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRCEL-CELINE	Belgian Interregional Environment Agency
ISCED	International Standard Classification of Education

ISCO	International Standard Classification of Occupations
k	Number of clusters
km	Kilometers
LF/HF	Low-Frequency to High-Frequency heart rate variability ratio
MAP	Mean Arterial Pressure
MCA	Multiple Correspondence Analysis
MENE	Monitor of Engagement with the Natural Environment
METs	Metabolic Equivalents
MH	Mental Health
MS	Microsoft
NA	Not Available
NR	Nature Relatedness
NUTS	Nomenclature of Territorial Units for Statistics
OD	Operational Directive
OECD	Organization for Economic Co-operation and Development
OHH	Ocean and Human Health
PANAS	Positive and Negative Affect Scale
PM_{10}	Particulate matter smaller than 10 micrometers
PRS	Perceived Restorativeness Scale
PSS	Perceived Stress Scale
PTQ-T	Perseverance Thinking Questionnaire – trait version
Q	Quintile (or Quartile in Chapter VI)
QALY	Quality Adjusted Life Years
r	Pearson correlation coefficient
R^2	Coefficient of determination or the ratio of explained over unexplained variation
Ref	Reference
S	Supplementary
SCR	Skin Conductance Responses
SCV	Socio-cultural shifts in Flanders (in Dutch: Sociaal-culturele verschuivingen in Vlaanderen)
SD	Standard Deviation
SDG	Sustainable Development Goal
SE	Standard Error
SES	Socio-Economic Status
SF	Short Form
SF36MH	Short Form 36 Survey Mental Health subset
SOC	Sense of Coherence

SOPHIE	Seas, Oceans and Public Health in Europe
SPSS	Statistical Package for the Social Sciences
SRA	Strategic Research Agenda
SRT	Stress Reduction Theory
VLIZ	Flanders Marine Institute
T	Time
Table S	Supplementary table
UGent	Ghent University
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
VR	Virtual reality
WHO	World Health Organization
WIV-ISP	Scientific Institute for Public health (in Dutch: Wetenschappelijk Instituut Volksgezondheid)
y	Year


7°C



Chapter I

General introduction

1. Rationale

The scientific literature suggests that spending time near the ocean can provide meaningful benefits for human health and that understanding these effects may lead to societal changes that foster a better health and a more sustainable use of the ocean's ecosystem services. Ecosystem services are the benefits and disbenefits that people obtain from the ecosystem (IPBES, 2019), and humans have used coastal and marine environments throughout history to go beyond the essence of survival and to thrive in our existence (Charlier & Chaineux, 2009; Gillis, 2012). Not only has the ocean been providing seafood and pharmaceutical precursors and regulating the climate, it has also been delivering a source for recreation and leisure, aesthetic experiences and inspirations, and other cultural ecosystem services (Custodio et al., 2022; Hynes et al., 2018; Rodrigues Garcia et al., 2017). In a way, all cultural and other ecosystem services directly or indirectly influence the human health of coastal and non-coastal citizens. It seems that the ecosystem services of the ocean have attracted citizens to live near it or visit it occasionally. Now, almost 1 billion people in the world live within 10 kilometers of the coast (Reimann et al., 2023), and about 50% of all recreational activities involve a coastal or marine destination (Northrop et al., 2022). Remarkably, the scientific evidence about the effects of spending time at the coast on human health is still scarce. This dissertation investigates how being exposed to the coast impacts human health.

The ocean, marine biodiversity, and the ecosystem services that they deliver are facing various threats. Humans have been burning fossil fuels to meet the growing demands of the expanding human population, and the resulting emission of greenhouse gases (i.e., mainly CO_2 and CH_4) have warmed the ocean's surface temperature with 0.88 [0.68 to 1.01] degrees Celsius since the period 1850–1900 (IPCC, 2023). Humans have also been harvesting most of the pelagic and benthic fish stocks and have reshaped many of the coastal functions and scenery (IPBES, 2019). Within the scientific community, there is now a high level of confidence that these environmental changes are irreversible and will have long-lasting impacts for the ocean and its ecosystem services (IPCC, 2023). Although many actions have been taken towards a more sustainable interaction with the ocean globally, there is still a lot to be done to restore the ocean's ecosystem services to their original levels where possible and to use them more sustainably (Halpern et al., 2012; Figure 1). Importantly, the quality of the ecosystem services involved in tourism and recreation are particularly low (39%). That is because the coastal tourism sector is currently characterized by a poor environmental sustainability, a poor socio-economic resilience, and a worldwide high pressure and impact by travel and tourism demands (Halpern et al., 2012; Soshkin & Calderwood, 2022).

Figure 1: The Ocean Health Index from the assessment period 2012-2022 (average score = 69/100) and the themes on which it is based (Halpern et al., 2012).

The 2030 Agenda for Sustainable Development provides a shared goal among all the member states of the United Nations to work towards a sustainable relationship between human activities and the environment (UN, 2015). At its core lie 17 sustainable development goals (SDG's; e.g., 3 - good health and well-being, 11 - sustainable cities and communities, 14 - life below water), which identify what sustainability exactly is and what must be preserved and what changed to achieve sustainability. Due to the importance of the ocean for achieving the SDG's, the United Nations has flagged the period 2021-2030 as the Decade of Ocean Science for Sustainable Development (UNESCO). This initiative has been sprinkling new inspiration across the world to tackle human's needs by managing and using the ocean's services more sustainably. It relates the SDG's to coastal and marine areas, providing an umbrella concept to accelerate funding for fundamental and applied marine research across the world. In order to work, the emerging solutions must transcend disciplines, be cost-effective in the long term, and find support in local, national, and cross-country communities and policies (Fleming et al., 2021).

One of the many actions operating in the light of the Ocean Decade is research on the nexus between the ocean and human health (OHH; Fleming et al., 2019). The central aim of OHH research is to increase the evidence and our understanding about how the ocean influences human health. It also aims to investigate how more resilient societies may interact with the ocean more sustainably. As such, the idea is to accelerate societal changes that benefit both the health of humans and of the ocean. The concept originated in the United States, where it initially concerned the threats of harmful algal blooms, chemical and microbial pollution, as well as marine biodiscovery for medicinal drugs (Knap et al., 2002). A few years later, the concept was brought to Europe (Bowen et al., 2006; European Marine Board, 2013). So far, the movement has mainly given rise to perspective papers and policy-advising documents that adopt a transdisciplinary and salutogenic approach (Fleming et al., 2019; Legat et al., 2016; Nash et al., 2022; Pellens et al., 2021; Reamer, 2022; Sandifer et al., 2021). One example of such a document is the map of the many intertwined, positive and negative interactions between the ocean and human health (Figure 2). These interactions between the ocean and human health must meet the demands of different sectors in society (e.g. tourism, healthcare, food provision), but are also poorly understood and unsustainably exploited.

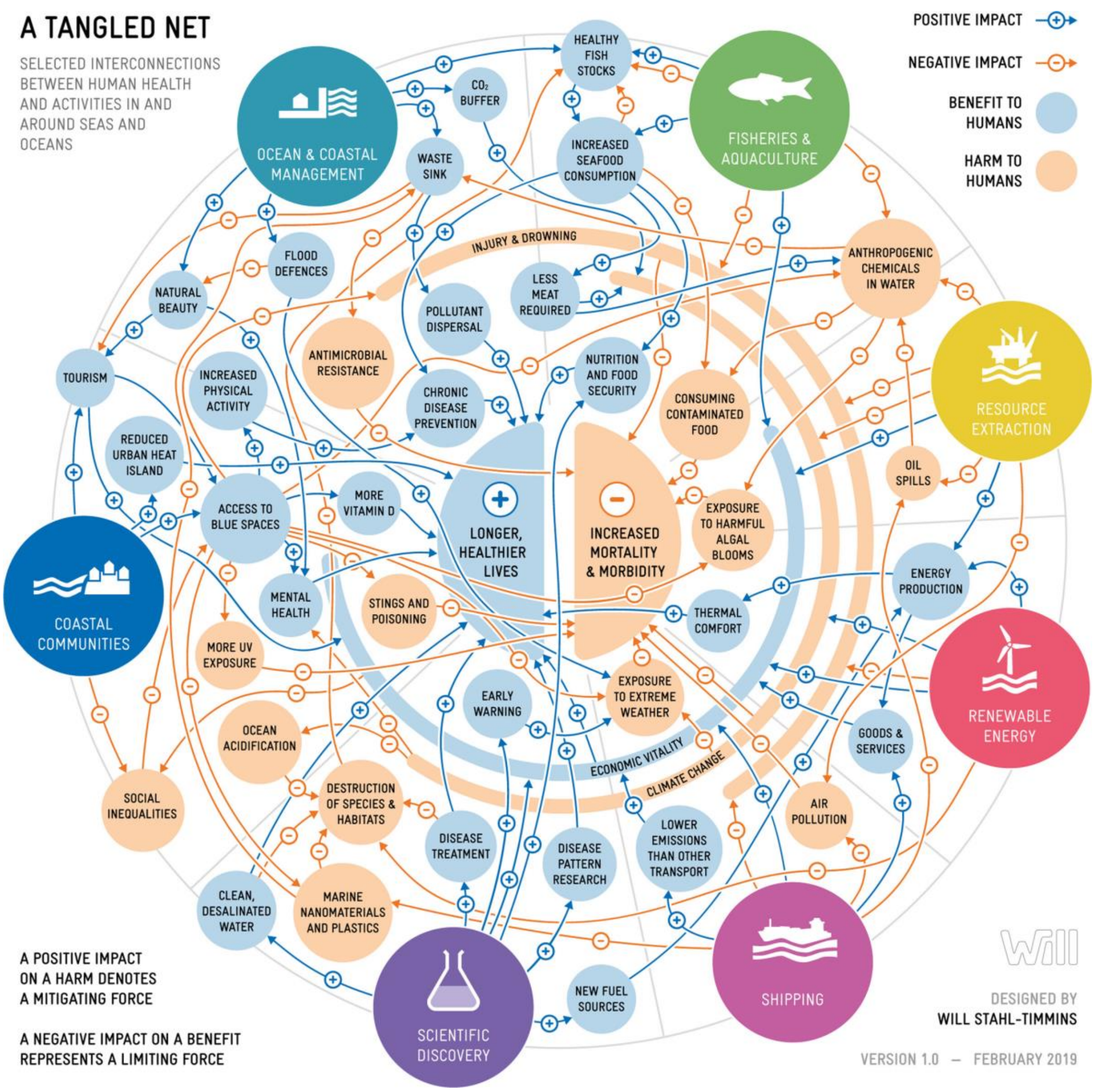


Figure 2: A tangled net depicting many of the hypothesized relationships to be addressed by ocean and human health researchers (designed by Will Stahl-Timmins; Fleming et al., 2019).

A decade ago, the European Marine Board already identified and explained how OHH research is "*a strategic research priority for Europe*" (European Marine Board, 2013). Recently, Europe's Horizon 2020 project "Seas, Oceans, and Public Health in Europe" (SOPHIE) proposed a more detailed strategic research agenda (SRA) for OHH research in the period 2020-2030 (H2020 SOPHIE Consortium, 2020). It proposed three key target action areas. Target action two of the agenda is particularly interesting in the light of this doctoral research, because it identified the key opportunities and challenges in the context of "Blue spaces, tourism and well-being".[1] This target aims to investigate how engaging with the coast (e.g. via recreation) is linked to human health and to the sustainable use of the ocean, it says: "*our vision is for improved individual and community physical and mental health and well-being through enhanced interactions with healthy blue spaces that are sustainably managed*" (H2020 SOPHIE Consortium, 2020).

The dependency between the individual's exposure to the coast and the gained experiences is central for linking the ocean to human health and vice versa. Coastal environments possess unique qualities that have shown to be particularly attractive for recreation (Gammon & Jarratt, 2019), and humans have been very creative in finding ways to enjoy the scenic beauty, massive amount of water, and long stretches of sandy beaches and dunes. People can exert many different activities in different coastal environments and under specific conditions. For example, people can walk or relax at the beach, explore the dunes, taste the local cuisine, visit natural or cultural heritage sites, or use the land, sea, or air for sports or mobility (Elliott et al., 2018).These activities would directly impose specific mental, physical, and social experiences that directly influence an individual's health. These experiences (and probably also the health status of the individual) in turn influence how much and in which way leisure time will be spent at the coast in the future (Dodds & Holmes, 2019; White et al., 2020). This interaction between exposure to the coast and the gained experiences indirectly links with human health via impacts on the coastal tourism sector (i.e., via job creation and economic revenues) and the healthcare system (i.e., via enhanced quality of life and avoided health care costs) (R. Buckley, 2022; R. C. Buckley & Chauvenet, 2022; Legat et al., 2016). On the other hand, the interaction between exposure to the coast and the gained experiences also interacts with the ocean. More specifically, the state of the ocean determines the scenery, perceptions, risks, and other factors that may impact the experience (Wyles et al., 2016). Additionally, developments of the coastal tourism sector alter the oceanic and coastal ecosystem for meeting the demands for recreation (Anfuso et al., 2017; Rangel-Buitrago et al., 2018), and the tourists' behaviors and ecological footprints may degrade the coastal and marine ecosystem (Jeyakumar et al., 2023; Portman & Behar, 2020; Tudor & Williams, 2008). Alternatively, being exposed to the coast may also impact individual pro-environmental behaviors via nature connectedness (Alcock et al., 2020; Berto & Barbiero, 2017; Britton et al., 2023;

[1] The term 'blue spaces' is an appealing term that has been used in both scientific and policy-informing documents to refer to environments with water bodies. These environments can be coastlines, but also predominantly green (i.e., dominated by vegetation) and urban environments with water features. This dissertation focuses on coastal environments, hence, the term 'blue spaces' is too general and thus avoided.

Rosa & Collado, 2019; Severin, Akpetou, et al., 2023; Whitburn et al., 2019), and acknowledging that exposure to the coast is valuable for human health poses a leverage for conserving the coastal and oceanic ecosystem and its services (Rosa & Collado, 2019; Whitburn et al., 2019). Thus, the ocean is inextricably linked to human health, and it is now imperative to better understand how exposure to the coast influences the coastal experience and human health.

While research from different separate disciplines is needed to gain knowledge about the coastal effects (i.e., 'multidisciplinary' science), an integration of the knowledge acquired from these separate disciplines is also required (i.e., 'interdisciplinary science'). Even more so, when interdisciplinary knowledge is co-created with other stakeholders (i.e., transdisciplinary science), societal challenges can be tackled most effectively. The research within this dissertation is transdisciplinary, because it uses knowledge and knowledge gaps identified from different societal stakeholders (e.g., policy documents, public narratives, trends in coastal tourism) to finetune the adopted approach and to adapt the research questions to the most pressing societal needs.

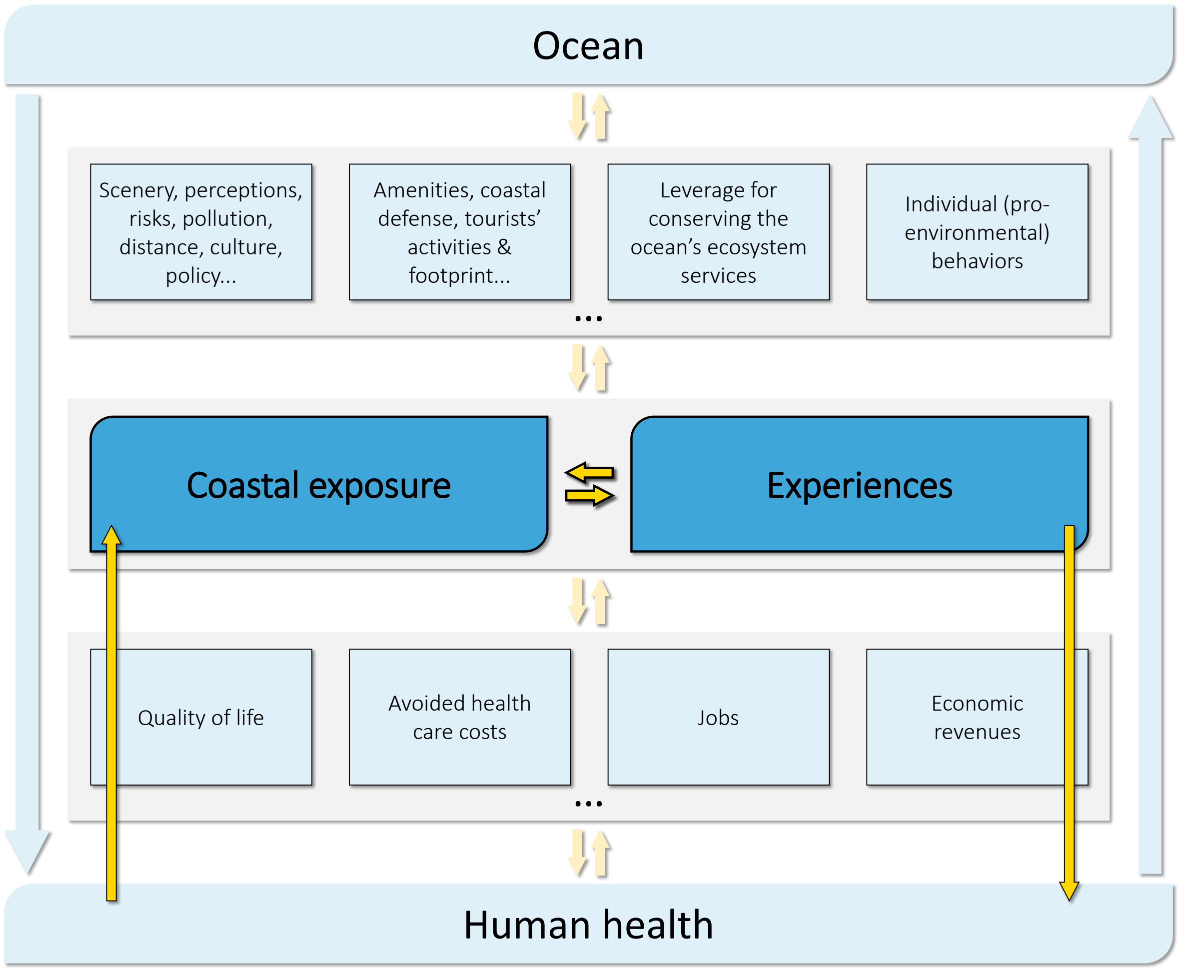


Figure 3: A schematic overview of how coastal exposure and the experiences with which they come link the ocean to human health and vice versa.

2. Health: what's in a name?

To investigate the effects of the coast on the coastal experience and on human health in this dissertation appropriately, a clear definition of 'health' and 'human health' is required. In the past, the term or concept 'health' could be interpreted in a different manner in different contexts. Furthermore, it also seemed that the 'ocean and human health' topic to which this dissertation is attached does not provide a specific and univocal interpretation of health. In this section, the contexts and meanings that have been given to health and to human health in the past are outlined, after which a 'specific approach to health' is conceptualized and a univocal interpretation for 'human health' is defined.

2.1. Previous approaches to health

The existing definitions of human health seem to be one of the most solid starting points to define health in general, albeit about the health of humans specifically. Human health was originally defined by the World Health Organization (WHO) as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" (1948). This original definition has been contested, because '*complete health'* would not be achievable and the dynamic nature of health was not included. Consequently, human health was later defined as "*a dynamic adaptive state, one that is not fixed nor absolute, and one that is constantly responding to environmental, social, biological, emotional, and cognitive conditions or states*" (Lovell et al., 2018). This definition was supplemented with the notion that human health has three domains that are inherently connected to each other (Lovell et al., 2018):

1) mental or psychological, relating to emotional, cognitive, and behavioral functioning;
2) physical or physiological, relating to biomechanical functioning; and
3) social, relating to the relationship with others.

The term human health has been used interchangeably with the term well-being in research papers and policy-relevant reports (e.g., H2020 SOPHIE Consortium, 2020; White et al., 2020). Well-being concerns many dimensions that may include and go beyond the typical mental-physical-social dimensions of human health. Well-being typically also refers to the spiritual dimension, to a dimension of how well activities and functions can be executed, and to a dimension of personal circumstances, such as the family situation (Linton et al., 2016). In terms of language, one could argue that 'well'-being is purely about the positive aspects of human health, while human health is neutral and simply about 'being'. Nevertheless, all the aspects to which well-being refers are also closely dependent on the mental-physical-social dimension. Furthermore, since the term well-being was also in the original definition of human health by the WHO, well-being can also be viewed as part of human health. So, given their interchangeable uses, human health and well-being both seem to be about the same all-encompassing, multidimensional state of how a human being is doing, irrespective of whether it is considered bad or good.

The definition of human health has received a different connotation for the health sciences 'clinical medicine' and 'public health' (Arah, 2009; Rose, 2001). Clinical medicine has typically focused on the health of individuals and on individuals with a risk of being in sub-optimal health. As such, individual health refers to the importance of healthy individuals, to the clinical, biomedical support that is needed to maintain healthy individuals, and to the existence of underlying psycho-physio-sociological anomalies or clinical determinants that are likely to lead to changes in the health of an individual in the future (Arah, 2009). On the other hand, the field of public health has generally concerned the health of populations rather than of individuals, and has taken a more preventive approach on a societal level. In this perspective, population health is about the socio-economic, environmental, political, and other societal contexts that impact the distribution of good or bad health in a human population, and acknowledges that the health of a group of individuals is more than the summation of the individuals' health (Arah, 2009). For population health, an individual's health is not only about its mental, physical, and social state, but also about its contribution and relevance for the community or society as a whole. Although the discussion about the difference and overlap between the scientific fields 'clinical medicine' and 'public health' and between individual and population health is still ongoing, it is clear that one relies on the other and implicitly contains the other (Siekmann & Osborne, 2023).

In the last decades, several holistic approaches to health have been communicated in research and policy atmospheres to emphasize the need to prioritize the health of particular entities over others and to put the health of these entities in the context of a bigger issue or importance (i.e., mostly sustainability; Lerner & Berg, 2017). Here, the most often quoted approaches are shortly described. Since 'health' has been attributed to many different entities, parentheses are used to invite the reader to reflect on the actual meaning of the term 'health' when it is joined alongside other words. The 'One Health' approach primarily links 'human health' to 'animal health' as a way to combat the spread of zoonotic diseases (Keune et al., 2017; Roger et al., 2016), but it may also include 'environmental health' in the widest approach (Gibbs, 2014). 'EcoHealth' focuses on the 'health of human and environmental systems', and places more emphasis on the importance of ecosystem processes than in the 'One Health' approach (Roger et al., 2016; Waltner-toews, 2004). For the 'Planetary Health' approach, the 'sustainability of the health of humans' is prioritized, and the 'health of animals and ecosystems' are only given secondary relevance (Whitmee et al., 2015). For the 'Global Health' approach, the need for 'healthy animals and ecosystems' is largely neglected, and the focus is almost entirely on the 'health of humans' and 'the societal systems on which human health depends' (Lerner & Berg, 2017). The 'Ocean and Human Health'[2] approach may also be added to this list. This approach gives equal importance to the 'health of the ocean' as to the 'health of humans', and focuses on the linkages between the two (Borja et al., 2020; Fleming et al., 2019, 2021; Fleming & McDonough, 2014; Franke et al., 2020; Lloret et al., 2020). From these approaches, it is clear that the concept 'health' has been assigned to different entities and different characteristics of these entities (e.g., their state, fate, influential causal pathways). In sum,

[2] The topic has not been given a consistent name, and authors have referred to the topic as 'oceans and human health' or as 'ocean and human health'. It should be noted that there is only one ocean on earth (i.e., the global ocean; Halpern et al., 2012), hence the term 'ocean and human health' is more appropriate.

the lack of a clear definition of the concept ‘health’ has resulted in many different uses and interpretations, and it is likely that readers make their own assumptions about the entity in focus and the underlying motivation.

To foster a clear and transparent communication about the planned and executed science on health, it is useful to reflect on the characteristics that have been given to the concept health. This ambiguous uses and interpretations of health The previously-described interpretations of ‘human health’, ‘individual vs. population health’, and holistic health approaches demonstrate that the following characteristics have been given to the concept health:

- Objectivity: health has always been about the state of an entity that is defined in space at a given time (e.g., humans, animals, the ocean).
- Ability: health has concerned the potential of an entity to exhibit a particular intrinsic function (e.g., the ability to respond to a stressor).
- Causality: health has also referred to causal effects that are happening through time (e.g., effects on communities, predator-prey interactions).
- Desirability: health seems to have embodied a factor of desirability, a subjective notion about the likelihood of particular outcomes to arise at some point in the future that are considered to be detrimental for the state and abilities of the entity (e.g., sickness, loss of function, extinction).
- Flexibility: health may refer to different states, abilities, causal effects, and (un)desirable outcomes depending on the entity health is appointed to (e.g., ‘human health’ refers to the mental, physical, and social dimension of how people are doing, while ‘ocean health’ refers to the ocean’s biodiversity, ecosystem functions, and physical conditions).

2.2. ‘The specific approach to health’

A critical examination of the interpretations and characteristics that have been assigned to health highlighted the need for a new conceptualization of ‘health’ for this dissertation. The new approach is called the ‘specific approach to health’ to remind a reader or a user of the approach to the importance of specificity when communicating about health. Below, the characteristics that have been assigned to health are critically examined and used for conceptualizing the new approach to health.

That ‘health’ is about an objective state of an entity is considered paramount for its conceptualization, because this objectivity allows for a clear, well-defined, and neutrally-emotionally-loaded interpretation of the concept. This objectivity notion requires that the entity to which the health state is attributed should always be scaled in space and time for its ‘health’ to be conveyed clearly and interpreted accurately. Knowledge from physics seems to be the most appropriate baseline to accurately define the entity in space and time. Physics has taught humanity that all the matter in the universe is essentially made from elementary particles (e.g., electrons) that interact with each other via fundamental forces (i.e., gravity, electromagnetism, weak and strong interactions). Elementary particles make up atoms, which make up molecules and living organisms or substances (e.g., solid, liquid, or gaseous), and ultimately the world and the universe. By adopting this perspective from physics, an entity can be defined as all the elementary particles and their organization within one or more three-dimensional polygons in space of own choosing at a given time. For example, defining a human individual as the entity in focus may hold all the atoms, molecules, organisms, tissues, organs, and substances within the boundaries of that person's skin. Whether microbiota on the epidermal surfaces and other questionable cases are also included is up to the choice of the definer. Notice that scale is crucial for defining the entity, and that the previously described approaches to health simply gave a different importance to different scales.

A second crucial characteristic that has been assigned to health is about the ability of an entity to exhibit particular functions. Applying a physics-perspective on this ability factor requires the acknowledgement that the entity's future is intrinsically restricted by its current state at the specified time. For example, if a human individual is considered at a particular time T_a, then it can only exhibit those functions within its ability (e.g., a month-old baby can sleep, eat, and cry, but not walk nor talk; one month later, it will still not be able to walk or talk, but it most likely will in two years). In this sense, 'health' can be interpreted as the organization of the particles within an entity and how they may potentially change in the future. Although this ability characteristic is prone to be interpreted subjectively, it further opens up the opportunity to also interpret derivatives of health, such as 'health benefits', 'health disorders', and 'good health' under this specific approach. For example, health can 'improve' if the entity will be able to perform more functions or exert particular functions more effectively (e.g., the ability to run faster).

The physics approach is completely applicable to any other scientific discipline. More specifically, the physics approach argues that there is a logical four-dimensional (i.e., x, y, z, t) explanation for every phenomenon in the universe. Essentially, different disciplines are concerned about different entities in space and time, and all disciplines can be approached with physics. Here are some examples of taking such a physics perspective on related disciplines: the field of medicine is about restoring the original state and abilities of human beings; psychology is concerned with the thoughts, feelings, and behaviors that arise from the state and abilities of the brain and body, with neurology explaining the linkage between brain morphology, functioning and psychological outcomes; the social, political, and epidemiological sciences are concerned with the distribution of different human entities and how humans' states vary according to their interactions with other human and material entities; evolutionary (human) biology and anthropology are primarily concerned with the states and abilities of human populations and cultural practices and how they vary through time; biochemistry and physiology are concerned with the state of molecules, cells, and tissues and their abilities to sustain life forms; and economics is in essence about how humans interact with money as physical bank notes or as electrons stored in the memories of bank accounts. It should be noted that there are still many gaps in our understanding about the elementary particles. However, for now, the physics approach seems to be the most objective and clear approach to define health.

The other characteristics given to health can be used to further refine the specific approach to health. By building further on the physics perspective, it becomes clear that the existence and behavior of each entity, how big or how small, inevitably causes changes in other entities over time, and that all entities vary in time according to a complex and dynamic blend of causes and consequences. This relates to the causality and desirability characteristics that have been given to health in the past.

The causality characteristic raises the question about whether causal influences should be considered as an integral part of the health state of an entity. For example, one could view the health of a human individual at timepoint T_a (e.g. now) as the simple three-dimensional organization of particles within the boundaries of that individual's skin. In this case, there are no causes or consequences, and the state of the individual can be seen as if it would be frozen in time. Alternatively, one could also view the health of an individual at time period T_a to T_b (e.g. today) as the displacement of the particles in the individual. In this case, the resulting physical movements, thoughts, feelings, etc. can be seen as part of the state and ability of the individual. However, the influences of the external entities that cause the individual to behave the way it does (e.g., the individual is invited to visit a friend) should not be considered as part of that entity's health. Remember that the world is a complex blend of causes and consequences, which makes all entities connected to each other via causation. In this sense, if the health of an entity would also be about the influence on and of other entities, the concept of health would be all-encompassing. Therefore, the specific approach to health defines the state of entity and its ability to change over time as part of health, but not the causal influences of other entities. So, restricting health to be purely about the state and ability, and not about the processes or external entities that are influencing it, the concept of health remains specific and clear. The desirability characteristic seems highly inappropriate to be assigned to health, because it is never fully certain what the future will be, and the desirability of a future scenario may differ depending on who or for what entity in the future is targeted. As a last note, defining health to be about the state of particles in entities defined in space and time makes it highly flexible and applicable for all entities, while previously health had to be used metaphorically. For example, previously, 'human health' acted as a metaphor for 'ocean health'. Thus, for science, it seems important to define health as something that is objective and something that is certain and accurate. Therefore, the causality and desirability characteristics given to health are not taken along for the definition of a new approach, and the physics approach makes that health keeps its flexibility and is disposed of its metaphoric use.

From the critical examination of the characteristics previously given to health, a new definition of health can be constructed. In this dissertation, the new approach to health is called 'the specific approach to health' and defined as "*an approach that interprets health as a dynamic and adaptive state of an entity defined in space and at a defined time point or period and the changes that it can potentially exert; if the entity and the time point or period is defined, then the health of the entity is what it is and what it can do, and not what it influences or what it is influenced by, at that defined time*". That health is dynamic means that it can vary in time without an external causality linked to it (e.g., a heartbeat of an individual). That the health of an entity is adaptive means that it is dependent on the presence and influences of other entities (e.g., an individual that talks to another person). The remainder of the first part of the definition describes the ability characteristic of health:

it describes that health is also about the changes or actions that the entity can exhibit, but not necessarily actually does. The second part of the definition explains that although health is adaptive, health is only about the entity that is defined in space and time, and not about the external causal pathways linked to it. More specifically, the health of an entity is not considered to be about what causes it to change nor what it causes to change, it is simply about the entity itself. As such, the interpretation of 'health' throughout the thesis can be done without underlying assumptions about causal influences of overarching entities (e.g. 'health of the ecosystem'), and the meaning of health is assured to be always the same and irrespective of the entity and time frame it is appointed to. In the next section, the specific approach to health is used to define the health of humans, or human health.

2.3. The interpretation of human health in this dissertation

In this dissertation, human health is defined by applying the specific approach to health on human beings. The entity is defined as all living human beings (i.e., all molecules and organisms within and on the boundaries of humans' skins, not clothes) and the time reference is defined as from now until the infinite future. As such, human health is defined as "*the dynamic and adaptive state of all human beings that exist now and in the infinite future and the abilities that all living human beings can potentially exert; from now on until the infinite future, human health is what all living human beings are and what they can do or become, and not what they are or will be influencing or what they are or will be influenced by*". It is one of the many potential specifications one could make from the specific approach to health. By defining the entity as 'all human beings', entire societal sectors (e.g., economic, health care, tourism) are not disproportionally targeted and the material, non-biological, aspects of these sectors (e.g., buildings, economic metrics) are neglected. By not specifying mental, physical, or social dimensions of human health, as in the previously published definitions (Lovell et al., 2018), the interpretation is also not restricted to them, yet encompasses them all. After all, it is simply about the organization of the particles within all living human bodies and their potential organization in the future that matters. This does not mean that human health is purely physical. A correct interpretation of human health in this dissertation can perfectly hold translations of what the organization of the particles mean for psychological and social concepts. That is because people's abilities are also part of the interpretation, such as abilities to think, feel, have a heartbeat, react to stress, communicate with others, etc. Furthermore, this new definition simply defines what can be interpreted under human health, and not how it is meant to be implemented. In the remainder of this dissertation, the term 'human health' is used in the same way as when this new definition would not have been presented. Similarly, derivatives, such as 'mental health', 'general health', 'health benefits' are still used, for which the added meaning to these derivatives comes from the adjacent words, rather than the interpretation of the word health itself.

In conclusion, this section provided a background on the use and meanings that have been given to health in the literature and formulated a new 'specific approach to health' and a new definition of human health. These definitions and insights should be used when interpreting matters on health in this dissertation. The specific approach to health and new definition for human health set clear boundaries on what this dissertation is about: it is about how the state and abilities of living human beings change in response to a particular type of exposure of the coast. The specific approach to health does not set any boundaries on the underlying motivations for investigating the topic, although there should be a logical potential or actual link to the defined entity. For this emerging research topic, the overarching motivation is that understanding the effects of the coast on human health is important, because these effects are ultimately linked to how sustainable the oceanic and coastal ecosystem is used and to how much we, as humans, can thrive on this planet (Figure 3). The motivation also includes that there are several potential societal applications that may arise from the acquired knowledge (e.g., health care applications). The next sections in this introduction describe additional contextual information about mental health and stress and about the literature on the effects of the coast on human health and the tackled knowledge gaps.

3. Mental health and stress

Target action two of the SRA for OHH research in Europe (i.e., “Blue spaces, tourism and well-being”) not only aims to work towards a more sustainable coastal tourism, but explicitly recognizes that the ocean may improve mental health in particular (H2020 SOPHIE Consortium, 2020). Currently, there seems to be a high prevalence of individuals with a sub-optimal mental health. More specifically, approximately one out of six people suffer from mental illness in Europe, and poor mental health has come increasingly to the attention of independent multinational organizations (OECD & European Commission, 2020; WHO, 2019). Good mental health is required for optimal psychological and physical functioning, maintaining healthy relationships with others, and coping with individual, structural, and community risk factors (WHO, 2012).

The problem of poor mental health is multifaceted. Apparently, contemporary lifestyles and cultures have nourished a growing pressure on individuals’ mental health, a pressure that has exceeded the capacity of the current health care system. Undeniably, many nations’ mental health care facilities are currently underserved and are often inaccessible and unaffordable, or at least perceived to be so (WHO, 2019). An additional concern is that individuals in sub-optimal mental health are stigmatized and discriminated against, which causes discouragement and avoidance towards seeking help (WHO, 2022b). The current therapies that are endorsed by the WHO include psychosocial interventions (e.g., cognitive behavior therapy) and the use of psychotropic medicines (WHO, 2022b). Although these interventions have shown some efficacy, their brief and unsustainable nature often results in relapses (Triliva et al., 2020). The COVID-19 pandemic has drastically increased the prevalence of mental health burdens, which has put additional pressure on the healthcare system to find new and more effective therapies (Dedoncker et al., 2021).

To combat poor mental health, innovative multi-sectorial changes are needed and new promising therapies should be proposed (WHO, 2022b). In this respect, coastal and other natural environments seem to be especially promising, because they are usually quite accessible (real or virtual), cost-effective, and socially endorsed to visit (Charveriat et al., 2021; Filipova et al., 2020; Short et al., 2021). Therefore, researchers have increasingly investigated how outdoor environments, such as the coast, may act as “the ultimate healthcare system” (UNEP, 2019). Before thinking about how spending time at the coast can benefit mental health, it is crucial to understand the drivers of mental health and of mental disorders.

Mental disorders are characterized by clinically significant disturbances in an individual’s cognition, emotion regulation, or behavior, and inherently poses a higher risk for (attempted) suicide (WHO, 2022b). Depression, anxiety, and adjustment (e.g., burn-out) disorders are the most prevalent mental disorders and may have life-long impacts on an individual (Almén, 2021; WHO, 2022b). There are several factors that may manifest as either risk or protective factors: e.g., the genetic, life-history, and socio-economic background and external social/societal and environmental phenomena (Llorente et al., 2018; Schneiderman et al., 2005; WHO, 2012). They are highly individual-specific and may manifest differently in different layers of society. Although risk factors usually fall outside a person's control, resilience can be strengthened by developing social, emotional, cognitive, and behavioral skills, by spending time in restorative environments, or by adjusting the reactions to the environment wherever possible and depending on a person's needs (Berto, 2014; Folke et al., 2021; Lymeus et al., 2020; Schneiderman et al., 2005; Schönfeld et al., 2017; Villada et al., 2017; von Lindern et al., 2017; White, Pahl, et al., 2013). Ideally, an individual must constantly accumulate such adaptions for it to be able to respond appropriately and timely to declines in mental health and to prevent the development of mental disorders.

Stress is a particularly interesting reaction in the context of mental health and the development of mental disorders, because the way an individual copes with stress dominates the risk for developing a mental disorder (Monroe & Cummins, 2015; Schneiderman et al., 2005). Stress is also particularly interesting for OHH research, because it is highly reactive to minor changes in an individual's immediate environment (Cacioppo et al., 2007). Stress constitutes of a psycho-physiological reaction to prevent an individual from experiencing harm in the case of an event or a set of internal or external conditions that are perceived to be (potentially) threatening (Cacioppo et al., 2007; see also Chapter IV). Since the stress-response is so crucial for life, it has been perfected throughout evolution. There are many different mental, physical, social, and environmental situations that may directly or indirectly impact the stress-level of an individual. Whether these situations are perceived as threatening depends on learned associations (i.e., memory stored in the hippocampus in the brain) and emotion-regulatory mechanisms (i.e., by the amygdala) within the limbic system of the brain (Cacioppo et al., 2007; Herman et al., 2005; K. H. Wood et al., 2014). Based on the interpretation of the situation, the brain will initiate a series of biomolecular and physiological pathways that prepare the body to deal with the event in a manner that is deemed appropriate.

In humans, there are two series of reactions that regulate the stress-response: mostly electrophysiological responses of the autonomic (i.e., sympathetic and parasympathetic) nervous system and mostly hormonal responses of the hypothalamic-pituitary-adrenal (HPA) axis (Golnaz, 2020; Herman et al., 2005; McCorry, 2007). It is important to note that each of these mechanisms has its own function: the sympathetic nervous system induces stress rapidly, while the HPA-axis ensures continuation of the stress-response and regular clean-up of the used molecules, and the parasympathetic nervous system (i.e., mainly the vagus nerve) facilitates recovery (Almén, 2021; Cacha et al., 2019). There are also many positive and negative feedback loops that enable to sustain the stress-reaction when needed or to initiate recovery when the stressor has passed (Cacioppo et al., 2007). As a result, the two series of stress-reactions mobilize the required emotional, cognitive, and physiological resources to deal with or to eliminate the threatening situation. These biophysiological mechanisms drive the psychological, physiological, and behavioral symptoms of stress. Psychological symptoms of stress include increased cognitive processing (often leading to unnecessary rumination and worry), emotional negativity and instability, and a loss of mindfulness, creativity, and inspiration. Physiological symptoms of stress include an accelerated heart and breathing rate, a more metronomic beating of the heart, tensed muscles, and sweating. Behavioral symptoms of stress include social isolation, restlessness, and decreased behavioral control.

Fluctuations in stress are normal and usually fall within the boundaries of one's resilience. However, stress can become problematic when its magnitude is repeatedly inappropriate for the prevailing conditions, or when there is insufficient recovery after the stress-response (Steffen et al., 2016). More specifically, the mobilization of molecules during the stress response causes depletions and excesses throughout the brain and body (Godoy et al., 2018). Ideally, an individual should not excessively overreact by wasting precious energy and resources, or react too little, because either the prevailing conditions or the faulty stress-response itself may result in damages to health in the short, mid, or long term. In order to acquire homeostasis again, an individual can for example take rest and sleep, be physically active, manage and regulate psychological information and thoughts, find distraction in non-harming situations, take the necessary food and fluids, regulate temperature, or do physical manipulations (e.g., physiotherapy; (Charveriat et al., 2021; Schneiderman et al., 2005).

Thus, the mind and body are structurally and functionally attuned to one another to allow an individual to pursue goals and to meet to the demands in current societies. Rather than to investigate therapies that can cure mental disorders, it seems more impactful in the long term to understand how one copes with stress, how recovery can be facilitated, and resilience can be strengthened (White et al., 2023). In this respect, exposure to the coast may attenuate unnecessary high stress-responses, facilitate recovery, and open up the mind to learn more quickly how to appropriately cope with stress.

4. The potential effects of exposure to the coast on human health

4.1. Historical context

Humans have adapted to their environment throughout human evolution, and understanding our adaptations to coastal environments is crucial before starting to investigate the effects of exposure to the coast on human health. In this section, a brief overview of a selection of historical events is given to frame human's relationship with the coast in the past.

Hominins started to disperse away from the Great Apes in central Africa around 1 million years ago in central Africa (Ragsdale et al., 2023). By about 200,000 years ago, different bipedal species of *Homo* had evolved and dispersed across Africa and Eurasia, including *H. habilis*, *H. erectus*, and Neanderthals (Ko, 2016). Then, humans, or *H. sapiens,* also dispersed out of central Africa, and seemed to have been more successful compared to the others that already expanded out of Africa (Ko, 2016; I. F. Miller et al., 2019; Neubauer et al., 2018; Ragsdale et al., 2023). Although the influence of coasts for the dispersal and fitness of *H. sapiens* is still under debate, it's highly likely that from around 300,000 years ago *H. sapiens* was able to forage shellfish along the shores of Africa and Europe (Gillis, 2012; Marean, 2010). As such, the brains of *H. sapiens* benefitted from an increased uptake of fatty acids, which enabled improved cognitive capacities, a greater reproductive success, better dispersal abilities, and increased behavioural flexibility (Marean, 2014; Will et al., 2019). As such, this brain-empowerment seems to have been the most important launchpad compared to all subsequent cognitive, social, and cultural developments (Gillis, 2012). However, there is still much to be resolved about human evolution in this prehistoric era, and although archaeologists and anthropologists have been focusing on the populations and genetic mingling in inland populations (Ko, 2016; I. F. Miller et al., 2019; Neubauer et al., 2018; Ragsdale et al., 2023), it is apparent that coastal environments have been crucial in human development, dispersal, and culture from the beginning (Marean, 2010, 2014; Will et al., 2019).

In the better-known historic era where civilized humans roamed and reshaped the earth, the coast was not only a source of food and mode of transportation, but also important for strengthening social bonds and improving mental and physical health. Since the Roman period, many bathing facilities for thermalism (i.e., the use of cold and heat to improve human health) and thalassotherapy (i.e., the use of seawater to improve human health) emerged at the shores and inland of Europe as places for cultural gathering and revitalization of the body and mind (Boterberge et al., 1987; Charlier & Chaineux, 2009). During the Middle Ages, the bathing culture came in decay due to a cultural shift towards using water for more hygienic reasons and restricting bathing to more private spheres. The culture of visiting the coast for various recreational activities finds its origin in the late 18th century (Boterberge et al., 1987). Then, royals and rulers reintroduced 'bathing in seawater' for their own use and started to spend their leisure time along the shores of Europe, particularly in Ostend and along the other Belgian, French, and English coasts. In part also due to the construction of railroads to the sea, the coast quickly became popular for the working bourgeoisie, who had just been granted at least the Sunday as time off in the early- and mid-19th century. Interestingly, the lower classes seemed to copy the leisure behaviors from the higher classes, which would have improved the former's social and cultural status (Boterberge et al., 1987). The reasons for visiting the coast were to relax, do nothing, and enjoy a pleasant time off, and these reasons have largely remained unchanged until today (Elliott et al., 2018; Westtoer & De Kust, 2018). It should also be noted that many of the spa's and bathing facilities have remained popular until today. As such, the conception that the properties of the coast, such as the seawater and -air, are healthy has been an essential part of human cultural development at the coast. Considering all these historical, motivational, and cultural insights, it makes sense that whole villages and cities emerged at the entry roads and railway stations along the coasts in Europe with only one reason: to give a revitalizing experiences for the coastal tourist (Boterberge et al., 1987; Charlier & Chaineux, 2009).

While the general public does not seem to visit the coast for health-related reasons (Elliott et al., 2018), their motivations for visiting the coast are related to health from a scientific perspective. More specifically, leisure activities in restorative environments form an essential part of humans' lives and, although not required for survival, they foster emotional, cognitive, and physiological capacities that allow to stay on top of the pursuits and challenges of everyday life (Gammon & Jarratt, 2019). Furthermore, that spending leisure time at the coast also contributes to one's social and cultural status should also receive important notion. Social status has been important throughout evolution for ensuring access to vital resources and for improving fitness (Korzan & Summers, 2021; Sapolsky, 2004). Now, one's subjective social status has been shown to impact exposure to social stress (Cundiff et al., 2020), levels of affect and various other health outcomes (Knight, 2022; Rahal et al., 2020), and even health-behaviors (Kraft & Kraft, 2021).

Scientific research about the actual effects of being exposed to the coast on human health was probably initiated by the German doctor Cari Mühry (in 1841 at the age of 34), who died after returning from having visited all the thalassotherapeutic facilities in his region and before he could publish his analytical findings (Verhaeghe, 1843). Louis Verhaeghe (1811-1870) is a better-known medical doctor, surgeon, and obstetrician who retrieved Mühry's documents for further research, and whose life was devoted to understanding the medical potential of the coast (Pirlet, 2016; Verhaeghe, 1843). Verhaeghe prescribed regular immersion in the sea itself or in (warm) seawater indoor for a period of weeks to patients with various complaints, including intestinal, muscular, cardiovascular, and neurological symptoms (Boterberge et al., 1987; Verhaeghe, 1843). Some areas along the coast were even exclusively devoted to these thalassotherapeutic practices, such as in Ostend in Belgium. Verhaeghe claimed that the immersion in the sea and contact with the seawater resulted in a stronger pulse, deeper breathing, increased appetite, more functional skin, and an overall revitalized and stronger body (Verhaeghe, 1843). He wrote that a first initial reaction by the nervous system would result in an initial shock experience, while a subsequent reaction would mobilize the body's resources to cope with the salty water. This mobilization of resources would result in feeling extraordinarily vivid. At some point during the immersion, the body's reactions would turn negative, so he proposed that regular, relatively short, immersion was necessary over the course of several weeks to optimize the positive effects of the coast and to avoid the negative effects (Verhaeghe, 1843). Although Verhaeghe's descriptions provided some insights about the benefits of exposure to the coast, they do not explain why coastal environments now attract so many visitors that usually want to experience the sea from land. Furthermore, although they were very detailed, they were not quantitative nor peer-reviewed.

4.2. Current evidence

Modern peer-reviewed scientific studies about the effects of the coast on human health are scarce. Nevertheless, there is a huge body of literature, both individual studies, reviews, and meta-analyses, that describe how natural environments influence human health (Aerts et al., 2018; Dzhambov et al., 2018; Gritzka et al., 2020; Hartig et al., 2014; Markevych et al., 2017; Mygind, Kjeldsted, Hartmeyer, Mygind, Bølling, et al., 2019; Stevenson et al., 2018). However, the conclusions from these studies do not necessarily apply to coastal environments. That is because many of these studies postulate that the type and dose of nature co-determines the health benefits (Kabisch et al., 2021; Marselle et al., 2015; Ode Sang et al., 2016; Van den Berg et al., 2014; White, Pahl, et al., 2013), and coastal environments harbor different types of nature and can be highly urbanized. Importantly, coastal visitors and residents are likely to move through both natural and urban environments along the coast (Elliott et al., 2018), which complicates the assessment of the effects of the coast on human health. Given the difficulty of applying nature-and-health research to the coast and other environments with water, a smaller body of literature has at least considered that blue spaces (i.e., those with a prominent water body) are different from green spaces (i.e., natural environment in general) and may thus create different effects and mechanisms (Britton et al., 2018; Gascon et al., 2015, 2017; Geneshka et al., 2021; Georgiou et al., 2021; Hermanski et al., 2021; Smith et al., 2021; Völker & Kistemann, 2011; White et al., 2020). In this context, White et al. (2020) proposed an interesting conceptual framework that mapped the different ways of exposure, the potential outcomes, the pathways between them, and influential factors modifying the effects (Figure 4).

The framework of White et al. (2020) outlines that residential proximity to the coast determines how an individual is exposed to the coast (i.e., intentional, incidental, or indirect), and what benefits can be transferred (Figure 4). Further, it shows that exposure to the coast may induce mediators (i.e., restoration, instoration, or mitigation) that are required to transfer the effects of the coast on human health (paths a and b). Note that the framework also explicitly recognizes that exposure to the coast may benefit planetary health and a more sustainable interaction with the environment via for example the induction of pro-environmental behaviors. Importantly, there are individual and situational moderators that are crucial for determining the type of exposure, the mediating pathways, and the health effects gained (paths c and d). More specifically, citizens and coastal visitors may differ substantially in their traits (e.g., demography, personality, mindfulness, socio-economic status, and cultural background) and states (e.g., current mental health), and each of these may co-determine the frequency and modus of being exposed to the coast and the health effects experienced (Boyd et al., 2018; Elliott et al., 2018). Similarly, the coast may present different environmental conditions depending on the time and place of the exposure, and each set of conditions may differently impact the likelihood of visiting the coast and the type of experience gained (Wyles et al., 2016). Consequently, in recognition of the pathways described further, each health outcome would be inevitably and ultimately the result of the assessed type of individual, the state that individual is in, and the exposure to the coast it has consciously or unconsciously experienced (White et al., 2020). The remainder of this section outlines the current evidence about the effects of residential proximity to the coast, intentional recreational coastal visits, and indirect exposure to the coast on human health via the mediating effects of restoration, instoration, and mitigation. In the discussion, I will elaborate on how the results of this doctoral research have contributed to strengthening the evidence for the pathways within this framework. The discussion also describes how evidence of paths a, b, c, and d in the framework is relevant for future societal, local, and personal actions that aim to improve mental and general health (Figure 4).

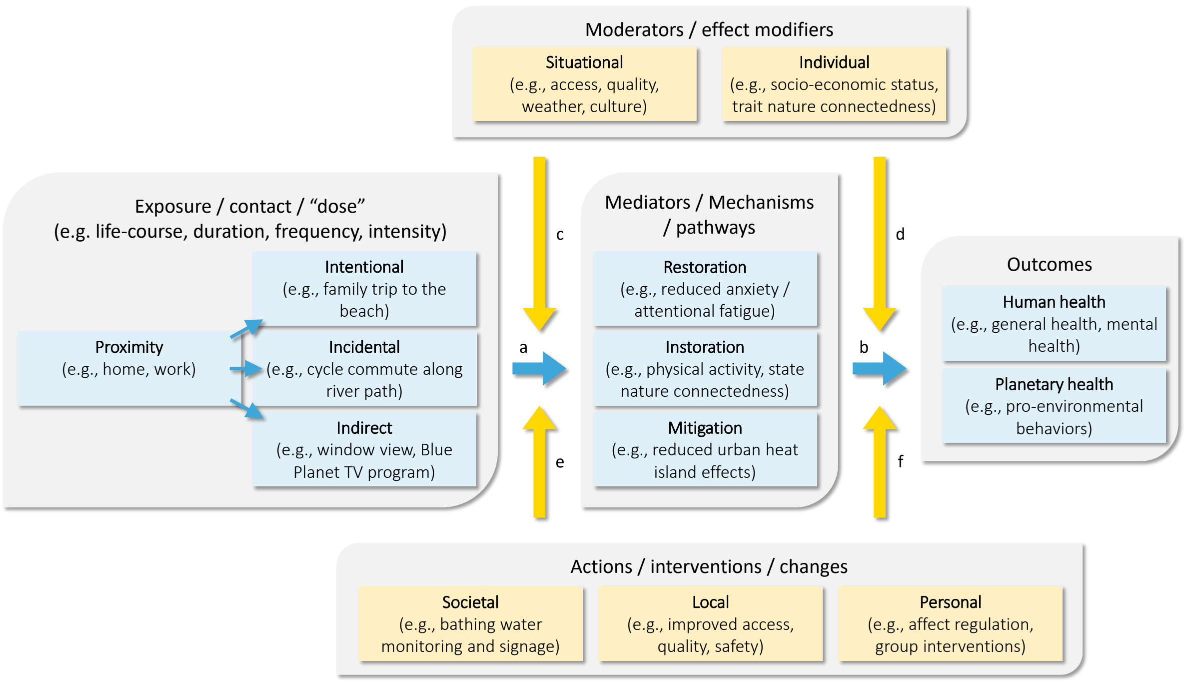


Figure 4: Overview of how exposure to the blue spaces, or the coast in particular, may impact human health and well-being and the influential factors herein (White et al., 2020).

4.2.1. Effects of residential proximity

There is now a good amount of evidence that links residential proximity to the coast to a better health. At the beginning of doctoral research, there was only evidence from England and Ireland that residing in closer proximity to the coast improves self-reported happiness, mental health, and general health (Brereton et al., 2008; Gascon et al., 2015; Wheeler et al., 2012, 2015; White, Alcock, et al., 2013). In England, these effects appeared not to be the result of healthier populations moving towards the coast (White, Alcock, et al., 2013), but rather an actual effect of coming to live by the coast (Alcock et al., 2015). However, in the meantime, the evidence on the effects on mental and general health have been strengthened by studies from Spain, Hong Kong, and England (Ballesteros-Olza et al., 2020; Garrett, Clitherow, et al., 2019; Garrett, White, et al., 2019; Pasanen et al., 2019; Wheeler et al., 2015). Recently, cross-country analyses that included samples from European countries, the United States, China, Australia, and Canada have established that residing in closer proximity to the coast improves self-reported general health (Elliott et al., 2023; Geiger et al., 2023). There are also suggestions that living closer to the coast would reduce the risk of developing breast cancer (Haraldsdottir et al., 2017), and that having a sea view from the residence would be particularly beneficial for reducing poor general or mental health (Dempsey et al., 2018; Garrett, Clitherow, et al., 2019; Nutsford et al., 2016).At the beginning of doctoral research, it was also unknown whether residential proximity to the coast was linked to making coastal visits more frequently. However, in the meantime, the same cross-country data has confirmed that the coastal visit frequency is tightly linked to residential proximity (Elliott et al., 2020, 2023; Geiger et al., 2023), and that the visit frequency is crucial for explaining the effects on health (Elliott et al., 2023). Taken together, these epidemiological studies mainly support the front (i.e., exposure) and end (i.e., eventual health outcomes) of White et al.'s (2020) framework, and not the pathways that are responsible for the effects of exposure to the coast on health (Figure 4).

4.2.2. The restoration pathway

Coastal environments, especially natural ones, would easily restore emotional, cognitive, and physiological resources after they have been depleted. These mechanisms have mainly been investigated with respect to the attention restoration theory (ART; Kaplan and Kaplan, 1989) and psycho-evolutionary stress-reduction theory (SRT; Ulrich et al., 1991). ART posits that coping with stress in everyday life depletes cognitive resources, especially human’s ability to direct and focus attention (Ohly et al., 2016). Safe and natural environments would be particularly effective for restoring these directed attention resources, because such environments would easily induce soft fascination, give a sense of being away from stressors, have a large extent, and are usually compatible with one’s innate desires (Berman et al., 2008; R. Kaplan & Kaplan, 1989). Through the soft fascination for the environment, human attention diverts to the environment (S. Kaplan, 1995). As such, directed attention resources do not need to be addressed and the brain is given time to rebuild these resources (Stevenson et al., 2018). Although ART has received some contestation in the literature (Joye, 2018; Joye et al., 2022; Neilson et al., 2019), the theory seems to hold (Hartig, 2021; White et al., 2023).

Complementary to ART, SRT posits that natural environments are psychologically and physiologically restorative mainly due to our evolutionary adaptions to nature, and not to urban environments (Ulrich et al., 1991). More specifically, humans would have been adapted to recover quickly from stress in safe, natural environments, because new environments would be potentially threatening and individuals that had recovered completely would have had a higher chance for survival. Furthermore, SRT states that humans have not (yet) developed the ability to perceive outdoor urban environments as safe, which would now result in a higher restorative power of natural environments compared to urban environments (Ulrich, 1993). The restorative properties would be hardwired by human's physiological adaptions that generate both physiological and psychological restoration. SRT builds further on Appleton's prospect and refuge theory (Appleton, 1977), Orians's and Heerwagen's savannah theory (Orians, 1980; Orians & Heerwagen, 1992), and Wilson's biophilia hypothesis (Ulrich et al., 1991; Wilson, 1984). As such, coastal environments would be particularly restorative because they offer medium levels of prospect and refuge, have similar characteristics as savannah-landscapes with water (i.e., the water, sand, and distant views), and are largely natural.

Although both SRT and ART have received a lot of attention by the nature-and-health literature in the last decade, they are still being modified and refined based on the emerging literature (Berto, 2014; Han, 2018; Hartig, 2021; Ohly et al., 2016; Stevenson et al., 2018). Given the context of mental health and stress and humans' evolution introduced earlier, it seems reasonable to assume that both theories are complementary to each other and applicable to explain the effects of different types of environments along the coast. Note that both theories posit that the initial levels of emotional, cognitive, and physiological health should have been depleted prior to enabling the potential for restoration.

Evidence for the restorative effects of coastal environments is scarce. Coastal environments have been associated with the highest level of psychological restoration compared to other natural and urban environments (White, Pahl, et al., 2013). This makes that the restorative effects of coastal environments are particularly promising for revitalizing mental health. Qualitative studies have shown that psychological restoration is one of the many mostly positive emotions and emotion-regulatory mechanisms that are induced at the coast (S. L. Bell et al., 2015; Severin et al., 2022). The leisure state of mind or 'holiday feeling' can be considered as such another emotion, and coastal environments would be particularly good for entering the leisure state of mind (Gammon & Jarratt, 2019). There have also been reports about the physiological changes that underpin the coast's perceived benefits. More specifically, the sympathetic nervous system activity has shown to be reduced more in response to virtual remote beaches than to a virtual indoor environment (Anderson et al., 2017). Additionally, the heart rate variability was found to be healthier (i.e., higher) at the coast compared to in the city (Triguero-Mas et al., 2017). However, this latter effect was mainly attributed to the higher levels of physical activity at the coast, and not to the coastal environment per se (Triguero-Mas et al., 2017). Furthermore, an earlier study on post-menopausal women did not find physiological restoration effects in response to the coast (White et al., 2015). Beaches have been perceived to be fascinating, to have a large extent, to be good for being away, and to be compatible with one's desires (Wyles et al., 2016), but one study did not observe replenishment of cognitive resources and capacities (Emfield & Neider, 2014). Thus, the restorative effects of coastal environments have a high potential to contribute to combatting poor mental health in current societies, both on an emotional, cognitive, and physiological level, but evidence for these effects is still lacking.

4.2.3. The instoration pathway

Instoration happens when health is improved without the requirement of prior depletion of emotional, cognitive, or physiological resources. It is most often considered to be the encouragement of physical activity (or the ‘blue gym’ effect) and gathering with friends or family, the power of environments to strengthen the positive appraisal of social relations, the enrichment of positive emotions and memories, and the formation of attachment bonds and personal meanings to specific locations (Völker & Kistemann, 2011). Coastal environments mainly seem to be associated with masses of tourists that perform many different leisure activities at the coast, most of them involving walking and other non-sedentary movements with family, a dog, or friends (Elliott et al., 2018; White, Pahl, et al., 2016; White, Wheeler, et al., 2014). Coastal residents are more likely to meet the recommendations of the WHO for being physically active for at least 30 minutes a day, being less sedentary, and doing regular intense physical activity (Bauman et al., 1999; Pasanen et al., 2018; White, Wheeler, et al., 2014). These physical benefits also translated in a lower prevalence of childhood obesity at the coast in England (S. L. Wood et al., 2016) and a decreased degeneration of muscle tension in older adults in the UK (de Keijzer et al., 2019). In the scientific community, there has also been quite some emphasis on the benefits of water-based activities (Britton & Foley, 2020; Denton & Aranda, 2019; Drake et al., 2021; Faerstein et al., 2018; Foley, 2015, 2017; Leonard et al., 2020; Pascoe, 2019; Thompson & Wilkie, 2020; L. E. Wood et al., 2022). Although water-based activities are considered the most risky (Leonard et al., 2015; Merino & Prats, 2022), the completeness of the immersion, physical requirements, often social circumstances, exposure to many microbes, and thalassotherapeutic profits make it one of the best ways to experience the benefits of the sea (Tipton et al., 2017). Next to promoting physical activity, coastal environments would also promote positive social interactions with friends and family (S. L. Bell et al., 2015), and children also seem to enjoy these interactions more at the coast than in inland environments (Ashbullby et al., 2013). Obviously, if people have a good time at the coast, they would also develop some sort of psychological attachment to the place (S. L. Bell et al., 2015; Jarratt & Gammon, 2016; Stansfield, 1969), and this attachment can lead to diverse emotional enrichments, such as happiness (MacKerron & Mourato, 2013) and nostalgia (Severin et al., 2022). The coast can also act as a protective factor during global crises. For example, coastal residents reported to be less bored and worrying and to be happier than inland residents during the COVID-19 outbreak and the associated first-wave lockdown in Belgium (Severin et al., 2021). Due to the many studies about the effects of the coast on physical activity, and the strongly narrated testimonies of people’s emotional enrichment in previous qualitative studies (S. L. Bell et al., 2015; Severin et al., 2022), the evidence about the instorative effects of the coast is relatively strong (White et al., 2020).

4.2.4. The mitigation pathway

A last pathway explains that the influence of the ocean mitigates harsh environmental conditions. These mitigations mainly concern the buffered coastal climate and the fact that only half the amount of land can pollute the air. Coastal climates are buffered due to the seawater being cooler than the land in warm seasons and warmer in cold seasons. As such, the temperature in summer can be a couple of Celsius degrees cooler compared to inland (Papanastasiou et al., 2010; Ten Brink et al., 2016; Völker et al., 2013). At the coast, fewer clouds are formed, which may increase the solar irradiance and human’s vitamin D production (Cherrie et al., 2015). Besides the climatic conditions, the coast is also characterized by a better air quality (Viana et al., 2014) and lower NO_2-concentrations, except around commercial harbors and in the plume of heavily trafficked sea routes (Dauwe et al., 2019; Hautekiet et al., 2022; Pope & Dockery, 2006; Pope III, 2002; Viana et al., 2014). Sea air also contains marine algae, bacteria, and viruses and their derivatives that, when in non-toxic concentrations and inhaled, may train the immune system and reduce inflammation (Andersen et al., 2021; Asselman et al., 2019; Fleming et al., 2005; Li et al., 2024; Moore, 2015). It should be noted that, at least in western Europe, the general public has often attributed the healthiness of the coast to the relative high concentrations of iodine in the sea air. However, although the iodine concentrations are higher in coastal environments because of the influence of the sea, these concentrations proved to be far too low to result in any measurable or experienceable effect on health (Bringmans, 2007). Thus, the environmental conditions at the coast seem to be less harmful for health compared to inland regions. However, perhaps most relevant is that the favorable meteorological conditions determine how long an individual spends time at the coast and experiences the benefits for health (Elliott et al., 2019; Smalley & White, 2023; White, Cracknell, et al., 2014; Wyles et al., 2016).

4.2.5. Potential risks

While the coast has many potential benefits, one should always remain vigilant of the negative effects and potential risks, because these risks may cause harm to health or even result in death. These risks include drowning, microbial infections, algal toxins, injuries from sharp, hard, or pointy litter or rocks, harmful effects from pollutants in the seawater or air, stings by (jelly-) fish or other harm caused by marine and coastal wildlife, among others (Cristiane Pinto et al., 2020; Davison et al., 2021; European Marine Board, 2013; Fleming et al., 2014; Grellier et al., 2017; Lawes et al., 2021; Leonard et al., 2015). Although actual physical harm is seldom encountered at the individual level, the mere presence of these risks may divert the cognitive attention away from the other aspects of the environment. For example, litter has shown to diminish the restorative and instorative benefits by reducing the fascination for the environment and other prerequisites for attention restoration (Wyles et al., 2016) and by disrupting trust in the fellow visitors' care for the environment (Severin, Hooyberg, et al., 2023). Due to the presence of the sea, it seems that coastal environments pose more risks than inland environments. Although these risks can usually be easily avoided, avoiding the risks (e.g., staying out of the water) also means that people are less immersed in the environment and experience less of the benefits (Verhaeghe, 1843). It should also be noted that in the last decades, the risk of sea level rise, storm surges, and declined biodiversity (e.g., causing jelly-fish blooms) has increased, which may cause additional concerns and eco-anxiety among the public (UNEP, 2019; Whitmarsh et al., 2022).

4.2.6. Concluding remarks

The current scientific literature contains many individual studies that have helped to understand the potential pathways of exposure and of the effects. However, most of the investigated topics are merely supported by a few isolated studies, and no review nor meta-analysis has compared effect sizes in response to exposure to coastal environments and on mitigation and moderation pathways specifically (note that reviews on the effects of blue spaces in general do exist; Britton et al., 2018; Gascon et al., 2017, 2015; Geneshka et al., 2021; Georgiou et al., 2021; Hermanski et al., 2021; Smith et al., 2021; Völker and Kistemann, 2011; White et al., 2020). Notably, since the beginning of this doctoral research, two cross-country analyses have established that residing in closer proximity to the coast is associated with a better self-reported general health (Geiger et al., 2023), and that living nearer the coast is associated with more frequent visits to the coast, less exposure to residential airborne NO_2, more frequent physical activity and social contact, and a better mental well-being (Elliott et al., 2023). Furthermore, the effects of coastal environments seem to be particularly prone to be evaluated in a spiritual manner by the general public (Jarratt & Sharpley, 2017). However, non-peer-reviewed narratives of individuals outside the scientific community, how appealing or convincing as they may seem (e.g., Nichols, 2015), should not contribute to the scientific knowledge about the effects of the coast and the resulting policies arising from that knowledge. Given these remarks, this dissertation considered the knowledge about the effects of exposure to the coast on human health to be poorly understood.

4.3. Belgium in focus

Belgium seems to be an excellent area to investigate the effects of the coast on human health, because it is geographically small (yet complex) and its coast seems relatively similar to many other popular coastlines in the world. There are also many opportunities for recreation that are highly popular among national and international citizens. Yet, at the beginning of this doctoral research, no research had been performed about the effects of exposure to the Belgian coast (or blue spaces in general) on human health in Belgium. Therefore, and also because this research was funded with Flemish subsidies, the research within this dissertation focused on the Belgian coast. Below, more context is given about the geographic, touristic, and socio-economic characteristics of the Belgian coast and the status of mental health in Belgium. For more details, the cited resources can be consulted.

The Belgian coast is 65 kilometers long, is relatively straight, and has almost exclusively sandy beaches with high tides twice a day (Degraer et al., 2023). The entire coastal zone is characterized by ten densely-populated administrative coastal municipalities (cover 42%; approximately 340 000 inhabitants) and ten sparsely-populated hinterland municipalities (cover 42%; approximately 88 000 inhabitants; Coudenys et al., 2023). Within the borders of the coastal municipalities, 19.9% of the land is built (compared to 19.4% in Flanders), and 22% (compared to 14% in Flanders) has some sort of designation for conservation (Dauwe et al., 2019). The residing population at the coast is on average older compared to inland. For example, 43% of the population has reached the age of 56 years or older (Coudenys et al., 2023). The Belgian coast has also been the center for thalassotherapeutic practices during the 19th, and 20th century, of which many remnants still remain at the coast (Boterberge et al., 1987). In typical seaside resorts, a man-made dike serves as a giant boardwalk separating the beach from the apartments, stores, and residences in the city. On the dike, there are usually many tearooms and restaurants, which during high season often expand to the nearby beach with a temporary terrace. In between the seaside resorts typically lie dunes in different stages of development and other types of natural areas. The dike is relatively well accessible by car, bike, or public transport. There are five rail routes that have their final station at the Belgian coast (Ostend, Blankenberge, De Panne, Knokke – with preceding stops in Heist and Duinbergen, and Zeebrugge dorp). There is a continuous tram route and road along the entire coast to connect the fourteen seaside resorts with each other. Many seaside resorts also contain recreational harbors, and two have internationally commercial ports (Ostend and Zeebrugge). The horizon views across the sea are not always flat: commercial and recreational fishing and transport vessels often pass in front of the coast, and offshore windfarms are visible on clear days. Piers and breakwaters prevent the sand from being eroded and offer additional experiences for the visitors. In contrast to the seaside resorts near the shore, the hinterland is characterized by a much lower population density, vast areas of farmland and polders, and sparsely located small municipalities.

Tourism and recreation is vitally important for the coastal municipalities and hinterland municipalities, with in 2021 over 5.7 million arrivals and almost 30 million overnight stays in commercial (40%) and privately owned (60%) holiday accommodation and yearly between 16 and 19 million day visits (Vandaele et al., 2023). However, tourism also presents many pressures and challenges in the region. There is a marked seasonal trend in tourism at the coast, with warm spring and summer holidays overwhelming the coast with visitors, while colder, off-season days or weekdays present an abandoned, empty coast. This bring about pressures and challenges for mobility, livability, and economic stability (Vandaele et al., 2023). Additionally, the high and seasonal tourism demand also exerts pressures on the environment. This is especially due to the increasing intake of land for holiday accommodations, but also the pop-up of typical white beach cabins, beach bars, occasional festivals and other attractions on the beach, and the visitors' ecological footprint and waste (Vandaele et al., 2023).

The mental health of Belgian citizens is sub-optimal. Already before the COVID-19 pandemic, 33% of the population did not feel to be mentally well (Gisle et al., 2018; Renard et al., 2020), and 23% stated to have a neutral to bad general health (Tafforeau et al., 2018). Belgian citizens live in one of the most urbanized countries in the world, and 70% of them does not meet the guideline of the WHO to perform moderate physical activities at least 150 minutes per week (Drieskens et al., 2018). There is a growing need for high-quality natural environments for recreation, because the current therapies to restore mental health often result in relapse (Triliva et al., 2020; WHO, 2022b). After the COVID-19 pandemic, people have become more aware of the importance of the environment for maintaining good human health (Lenaerts et al., 2021), but there are still many uncertainties about how to leverage the benefits of the environment and the coast to improve people's mental health.

5. Knowledge gaps

The SRA for OHH research in Europe has identified key overarching research questions to guide researchers in addressing the most relevant knowledge gaps that need to be filled in order to be able to use blue spaces to combat the mental health crisis and to enable sustainable interactions with the ocean (H2020 SOPHIE Consortium, 2020). Below, they are framed irrespective of the geographical scope and to be specific for the coast.

A. What is the evidence for the effects of coastal environments on human health?

B. With regards to mechanisms and pathways:

   B.1. Through which interactions (type of activity, duration etc.) with different types of coastal environments does human health improve?

   B.2. Through which interactions does the risk of disease and/or physical issues increase?

C. How does increasing the human use of coastal environments affect the coastal and marine ecosystems and biodiversity?

D. How can we optimize OHH interactions in order to obtain physical and mental health benefits in a sustainable manner for all people and species?

These research questions should be addressed in the respective order. Given the limited literature about the effects of the coast on human health, the primary targeted should be increasing the evidence base (A) and increasing our understanding about the effects of the exposure and the affected health outcomes (B.1.). While doing so, the risks should be acknowledged and assessed (B.2), and the impact on the environment should be assessed (C). Only in a later stage the focus should be on how to make the OHH interactions optimized and more sustainable (D). In practice, studies should be designed as such that translation of the results to societal applications is possible, practical, and relevant.

The previous section demonstrated that coastal environments may contribute substantially to the health of its visitors and residents, but also that there is still a major knowledge void about the pathways by which the coast can improve health and mental health in particular (White et al., 2020; Figure 4). More specifically, increasing the evidence and our understanding requires insights in the aspects of the exposure that influence health, the diversity of health outcomes affected, the restorative, instorative, and mitigative mechanisms, and the individual characteristics that may impact the magnitudes of the effects (Georgiou et al., 2021; Hartig et al., 2014; Wheeler et al., 2012; White et al., 2020). The multidisciplinary nature of these pathways indicates that investigating the effects of the coast on health requires an approach where insights from various disciplines are needed, particularly from the health sciences, psychology, and sociology (Fleming et al., 2019). Transdisciplinary knowledge would make the conceptualized pathways in the framework of White et al. (2020) to be better evidenced and understood (Figure 4; H2020 SOPHIE Consortium, 2020).

6. Aims of this doctoral research

The general aims of this doctoral research were to gain evidence and to increase our understanding about the effects of coastal environments on human health (overarching research question A and B.1 of the SOPHIE SRA; Figure 5) by providing evidence for the conceptualized pathways in the framework of White et al. (2020; Figure 4). Five complementary studies were completed, which are described in detail in the five chapters that follow this introduction. The rationale behind these studies was to gradually increase the conceptual complexity in three stages. In the first stage, this project aimed to observe whether or not constant exposure to the coast, i.e., by residing near it, results in a better general health in Belgium. In this stage, the mediating effects of four hypothesized mechanisms (i.e., less mental distress, more physical activity, better social interactions, and better environments/air quality; Hartig et al., 2014) were also explored (Chapter II). Then, for the next two chapters, the focus shifted towards the restorative effects of the coast for mental health in particular, and not for physical or social health, because the coast has shown to be particularly effective for psychological restoration, though relatively few experimental studies existed to backup these claims (Triguero-Mas et al., 2017; White et al., 2010; White, Pahl, et al., 2013; Wyles et al., 2019). Another reason was that mental health is particularly relevant for general health, because it has an emotional, cognitive, and physiological component and is closely linked to social interactions and contexts and physical health behaviors. As such, in the second stage, two experimental studies were executed to reveal how different aspects of the coastal environment (i.e., different types of environments and components) impact mental health (Chapter III), and what psychological and physiological outcomes of mental health are reactive to one of the most popular and promising environments, i.e., beaches (Chapter IV). In the last stage, another observational study was chosen to gain perspectives about how the exposure (i.e., activities and social company during the visit) and the effects (i.e., self-reported experiences) are associated with individuals' geo-demographic, socio-economic, and health characteristics, i.e., how they are socially structured (Chapter V and Chapter VI). As such, this project meant to shed light on some crucial psychological, physiological, and social phenomena that could help us to understand the aspects of the environment that influence health, the psychological and physiological reactions to the environment, what internal mechanisms might explain these reactions, and the underlying social structuring of the exposure and of the effects (Figure 5). The specific aims that are tackled within each chapter are listed on the next page.

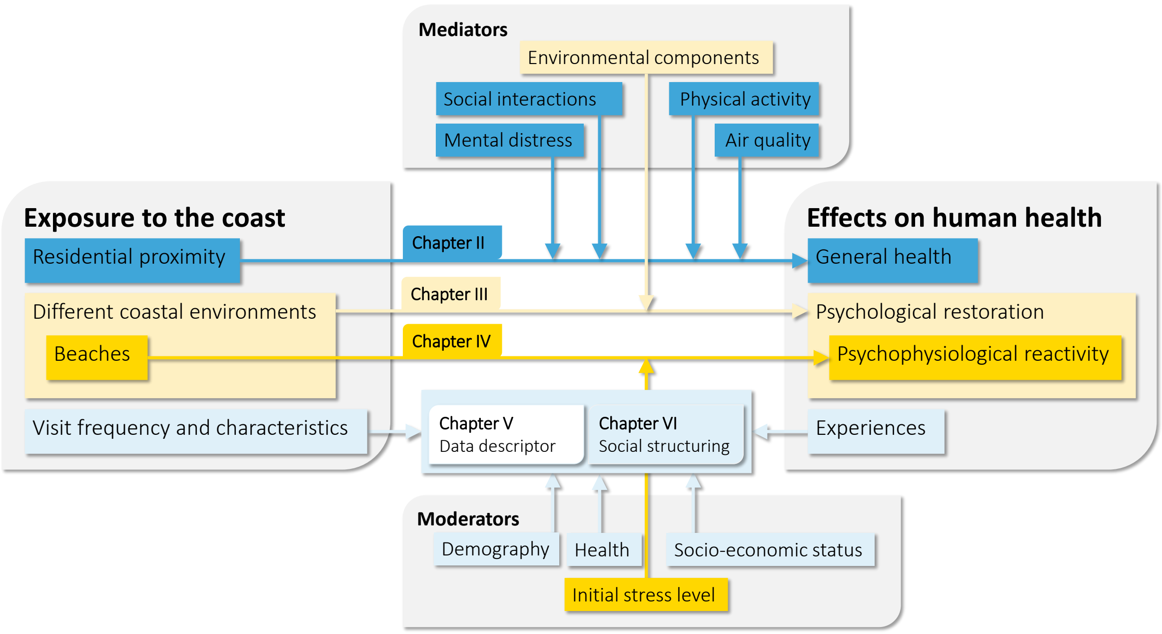


Figure 5: Conceptual diagram of this dissertation depicting the studied potential relationships between the coast and human health.

Aims of Chapter II (Hooyberg et al., 2020):

- ○ To determine the relationship between residential proximity to the coast and self-reported general health.
- ○ To reveal the mediating role of four hypothesized mechanisms (i.e., mental health, physical activity, social interactions and air pollution).
- ➢ In this epidemiological study, Belgian Health Interview Survey data (N = 60,939; 1997-2013; Sciensano) was combined with road-map and land-use data.

Aims of Chapter III (Hooyberg, Michels, et al., 2022):

- ○ To quantify the inter- and intra-environment variation in psychological restoration along the coast.
- ○ To quantify the mediating influence of naturally varying doses of natural and urban components and people in the environments.
- ➢ These aims were tackled by a lab-experiment in which 52 pictures were rated by Flemish students (N = 102, 18-30y, 83% female).

Aims of Chapter IV (Hooyberg, Michels, et al., 2023):

- ○ To quantify how diverse psychological and physiological parameters of stress respond differently to beaches, green, and outdoor urban environments.
- ○ To quantify the moderating effect of initial stress level.
- ➢ These aims were tackled by a lab-experiment in which 360° virtual-reality videos were displayed to adults (N = 164, 18-65y, 68% female), while physiological indices of stress were monitored and questionnaires on psychological outcomes were taken.

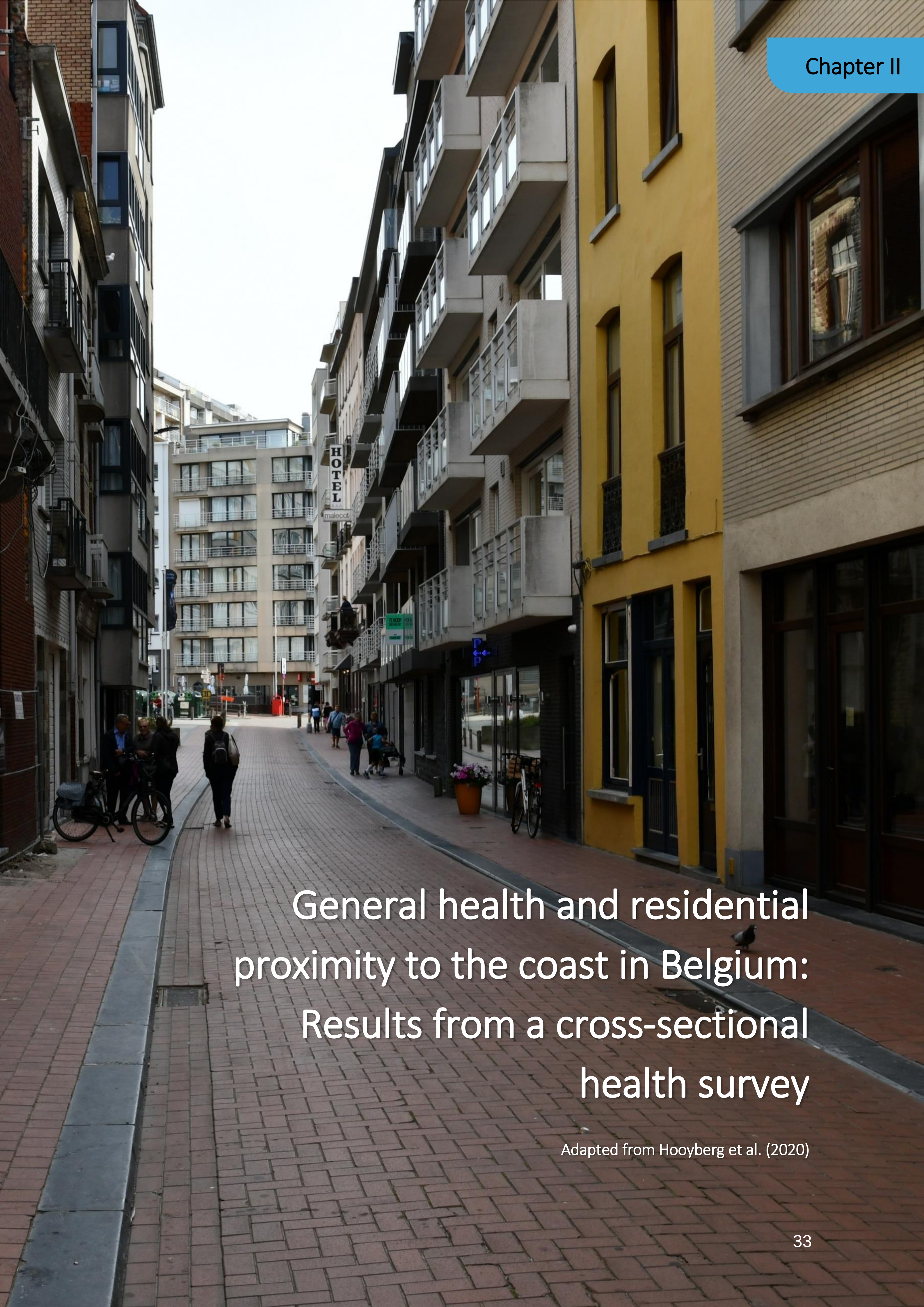
Aims of Chapter V (Hooyberg et al., revised after minor revisions in the journal *Scientific Data*; data at https://doi.org/https://doi.org/10.14284/625; Hooyberg, Roose, et al., 2023):

- To develop and describe a dataset that allows confirmatory and exploratory investigations on the relationships between exposure to the coast and parameters of health according to the principles of open data. More specifically, the dataset had to contain indices for residential proximity to the coast, the frequency and characteristics of coastal visits, the resulting mental and physical experiences, and the moderating roles of the individuals' demography, socio-economic status and health.
- ➢ Therefore, a survey was distributed among a representative panel of Flemish-speaking Belgian inhabitants (N = 1,939, 2023) and their visits to the Belgian coast in the previous year.

Aims of Chapter VI (Hooyberg et al., drafted for submission in the journal *Environment and Behavior*):

- To structure coastal leisure activities and types of social company in a multidimensional space in which each dimension exerts a unique structuring force.
- To reveal how the coastal leisure activities and types of social company covary with the season, frequency, and type (i.e., day visits vs. longer stays) of coastal visits, the experiences gained, and the demographic, socio-economic, and health characteristics of the individuals
- To identify clusters of individuals with similar leisure activity profiles and to describe them based on their locations in the multidimensional space and their association with the supplemented variables.
- ➢ Data from Chapter V were used to tackle these aims. We focused on the respondents that had reported to have visited the coast in 2022 (N = 1,302).


LE SYRTAKI BLANKENBERGE
GREEK & GRILL
RESTAURANT
SALONICA WHITE TOWER
SYRTAKI
TRADITIONAL GREEK RESTAURANT
POOL
BAR
EVERY NIGHT
CLUB DISCO
NOSTALGI



General health and residential proximity to the coast in Belgium: Results from a cross-sectional health survey

Adapted from Hooyberg et al. (2020)

Abstract

The health risks of coastal areas have long been researched, but the potential benefits for health are only recently being explored. The present study compared the self-reported general health of Belgian citizens a) according to the EU's definition of coastal (< 50 km) vs. inland (> 50 km), and b) between eight more refined categories of residential proximity to the coast (< 5 km to > 250 km). Data was drawn from the Belgian Health Interview Survey (N = 60,939) and investigated using linear regression models and mediation analyses on several hypothesized mechanisms. Results indicated that populations living < 5 km of the coast reported better general health than populations living at >50-100 km. Four commonly hypothesized mechanisms were considered but no indirect associations were found: scores for mental health, physical activity levels and social contacts were not higher at 0-5 km from the coast, and air pollution (PM_{10} concentrations) was lower at 0-5 km from the coast but not statistically associated with better health. Results are controlled for typical variables such as age, sex, income, neighborhood levels of green and freshwater blue space, etc. The spatial urban-rural-nature mosaic at the Belgian coast and alternative explanations are discussed. The positive associations between the ocean and human health observed in this study encourage policy makers to manage coastal areas sustainably to maintain associated public health benefits into the future.

Keywords

Blue space, Mental health, Physical activity, Social interactions, Air pollution

1. Introduction

Coastal regions are defined in the EU as within 50 km of the coast, and account for 40% of the European land area and population (Eurostat, 2013). Public health research related to the marine ecosystem has traditionally focused on reducing impacts by natural hazards and risks, and on improving human health by the maximal exploitation of goods and services such as seafood and novel pharmaceuticals (European Marine Board, 2013). It has long been acknowledged that exposure to marine and coastal environments may also improve health (Charlier & Chaineux, 2009). Systematic research into such benefits within the last decade has begun to discover the diverse role of coastal environments as an accessible public health resource (Cracknell, 2019; Gascon et al., 2017). While most literature has focused on exposure to the sea or beach specifically, the coast in general (including both urban and natural areas) also provides health benefits (Gascon et al., 2017). Coasts are often diverse and consist of a mosaic of urban towns, cities and harbors interspersed by rural and more natural beaches and dunes. Early work in England and Ireland suggested that populations living in proximity to the coast in general reported better general health and well-being compared to those living inland (Brereton et al., 2008; Wheeler et al., 2012; White, Alcock, et al., 2013).

This study investigates the link between self-reported general health and residential proximity to the coast, and additionally aims to identify the mechanisms underlying that relationship. Four likely mechanisms have been proposed to explain the health benefits from living in proximity to the coast, which are similar to those discussed for the relationships between health and residential green space exposure (e.g., parks and forests) (Gascon et al., 2015, 2017; Kabisch et al., 2015; Lahart et al., 2019; Jolanda Maas et al., 2009; Jolando Maas et al., 2006; Markevych et al., 2017; Nieuwenhuijsen et al., 2017; Van Aart et al., 2018; Völker & Kistemann, 2015; White, Pahl, et al., 2016). First, characteristics of coastal environments may divert attention from everyday routines and demands, consequently restoring those psychological resources that facilitate the reduction of stress and support positive mental health (Elliott et al., 2019; Garrett, Clitherow, et al., 2019; R. Kaplan & Kaplan, 1989; White et al., 2010; White, Alcock, et al., 2013; White, Pahl, et al., 2013). Psychological benefits, such as reduced depression, can even be obtained from having a view of water from the residence (Dempsey et al., 2018; Garrett, White, et al., 2019; Nutsford et al., 2016; Peng et al., 2016b), or by looking at marine wildlife (Cracknell et al., 2016, 2017, 2018; White, Weeks, et al., 2017). Second, coastal environments may support health by promoting walking and other physical activities (Elliott et al., 2015, 2018; Kerr et al., 2014). As such, a person is more likely to attain healthy levels of overall physical activity (Bauman et al., 1999; Pasanen et al., 2019; White, Wheeler, et al., 2014). Increased coastal physical activity can manifest in for example less childhood obesity (S. L. Wood et al., 2016) and slower decline in muscular strength among older adults (de Keijzer et al., 2019). Third, the positive social ambience in coastal environments may improve health by reinforcing positive interactions between individuals (S. L. Bell et al., 2015; Dzhambov et al., 2018; Hartig et al., 2014). Qualitative research, for instance, has demonstrated that children enjoyed family interactions most when visiting the beach compared to other (semi-

) natural environments (Ashbullby et al., 2013). Finally, the relative absence of traffic and industry at sea compared to on land may result in distinct physiochemical characteristics in proximity to the coast, such as reduced air pollution. People have been using the health-enhancing properties of coastal air since the nineteenth century (Charlier & Chaineux, 2009; Pirlet, 2016; Verkest, 1898). However, much less researched to date are the public health benefits that can be obtained from reduced air pollution in coastal environments (e.g., A Prüss-Ustün, J Wolf, C Corvalán, 2016; Davidson et al., 2005; Lu et al., 2015; Pope and Dockery, 2006; Pope III, 2002).

Despite the growing amount of health promoting effects described in literature, evidence which links (self-reported) general health with residential proximity to the coast is still mixed and originates from only a couple of countries such as the United Kingdom (Gascon et al., 2017). Moreover, studies which link this relationship with each of the four hypothesized mechanisms are scarce. So, the question remains if the described benefits and mechanisms can accumulate to a measurable increase in the self-reported general health of coastal populations across Europe. Therefore, this paper addresses these knowledge gaps with a twofold aim. First, this study explores whether positive relationships between self-reported general health and residential proximity to the coast exist in Belgium. Since no comparable research has been carried out in Belgium, we addressed the health-residential proximity relationship at two different spatial scales: one comparison is based on the EU definition of 'coastal' (< 50 km vs. > 50 km) and is contrasted against a more nuanced delineation (i.e., 0-5 km, >5-20 km, >20-50 km, >50-100 km, >100-150 km, >150-200 km, >200-250 km and >250 km), similar to that used in previous research (Wheeler et al., 2012; White, Alcock, et al., 2013). The second aim explores if any of the four hypothesized mechanisms account for the association between residential proximity to the coast and the self-reported general health of Belgian citizens. The mediation effects of specifically mental health, physical activity, social interactions and air pollution are tackled.

2. Materials and methods

2.1. Data

2.1.1. Health Interview Survey

Repeat cross-sectional survey data from the Belgian Health Interview Survey (HIS, N = 60,939, obtained through Sciensano in accordance with privacy regulations) were used to test both hypotheses. The HIS is a large national survey that collects data on demography (e.g., residence location, education and employment), health and well-being (e.g., perceived general health, long term diseases and limitations, pain, mental health and indices of quality of life) and other issues related to health behavior and lifestyle, the use of health care and social services, physical activities, and social contacts. It has been administered in 1997 (N = 10,786), 2001 (N = 12,770), 2004 (N = 13,831), 2008 (N = 11,938) and 2013 (N = 11,614) through written and oral questionnaires (still ongoing), using a stratified and multistage-clustered design. Respondents were stratified at the province level, and clustered at the municipality level and household level. Each year, a minimum of

3500 participants from the Flemish and Walloon regions, and 3000 participants from the Brussels region, were randomly selected based on their social number. The potential presence of a participation bias was acknowledged, and overcome by weighting each sampled individual based on age, sex, and household size to be representative of the population in the province of residence.

2.1.2. Self-reported general health

The outcome variable in this study concerns self-reported general health. This was derived from the question: "*How is your health state in general?*" Five possible answers ranged from '*very bad*' (scored 1) to '*very good*' (scored 5). This single item is one that is among the three variables forming the Minimum European Health Module, which was designed to allow comparable calculations of health expectancies across Europe (Robine et al., 2003), and is the same one as used in the European Health Interview Survey. Self-reported general health was assessed in all waves throughout the study period (i.e., 1997, 2001, 2004, 2008, and 2013) and only administered to respondents aged 15 years and older.

2.1.3. Residential proximity to the coast

Residential proximity to the coast has been associated with a variety of health outcomes, such as physical activity, self-reported mental and general health (Pasanen et al., 2019; White, Alcock, et al., 2013; White, Wheeler, et al., 2014). Residential proximity to the coast in this study was calculated as the distance travelled using the fastest driving route from the geographical center of the residential municipality to the nearest point at the Belgian coast (extended up to Breskens in The Netherlands, marking the boundary with the Western Scheldt estuary, Figure 6). To do so, the OpenStreetMap road network (OpenStreetMap contributors, 2018) and Eurostat coastline data (Nomenclature of Territorial Units for Statistics (NUTS), 2013) were combined in QuantumGIS 3.2.2 to generate a dataset of coastal destination points. Afterwards, the distance corresponding with the fastest driving route from the municipality centers to these points were calculated using the ArcGIS Pro 2.2.0 Network Analyst extension. Figure 6 illustrates the modelled origins, destinations, and fastest travel routes between them. On this map, it is clearly visible that most of the fastest travel routes involve the same highways through the country. In contrast with Euclidean distances as were used in previous studies (Brereton et al., 2008; Wheeler et al., 2012; White, Alcock, et al., 2013), it is assumed that these fastest travel routes are a good reflection of the real travel behavior of Belgian citizens. Figure 6 also illustrates that the GIS model predicts only a few accessible routes when nearing the Belgian coast. It should be emphasized that Belgian citizens are likely to deviate from these routes when nearing the coast to reach more remote areas along the coastline, such as dunes, smaller coastal towns, parking lots, etc. This geographical nuance near the Belgian coast has to be considered when interpreting Figure 6 and the results.

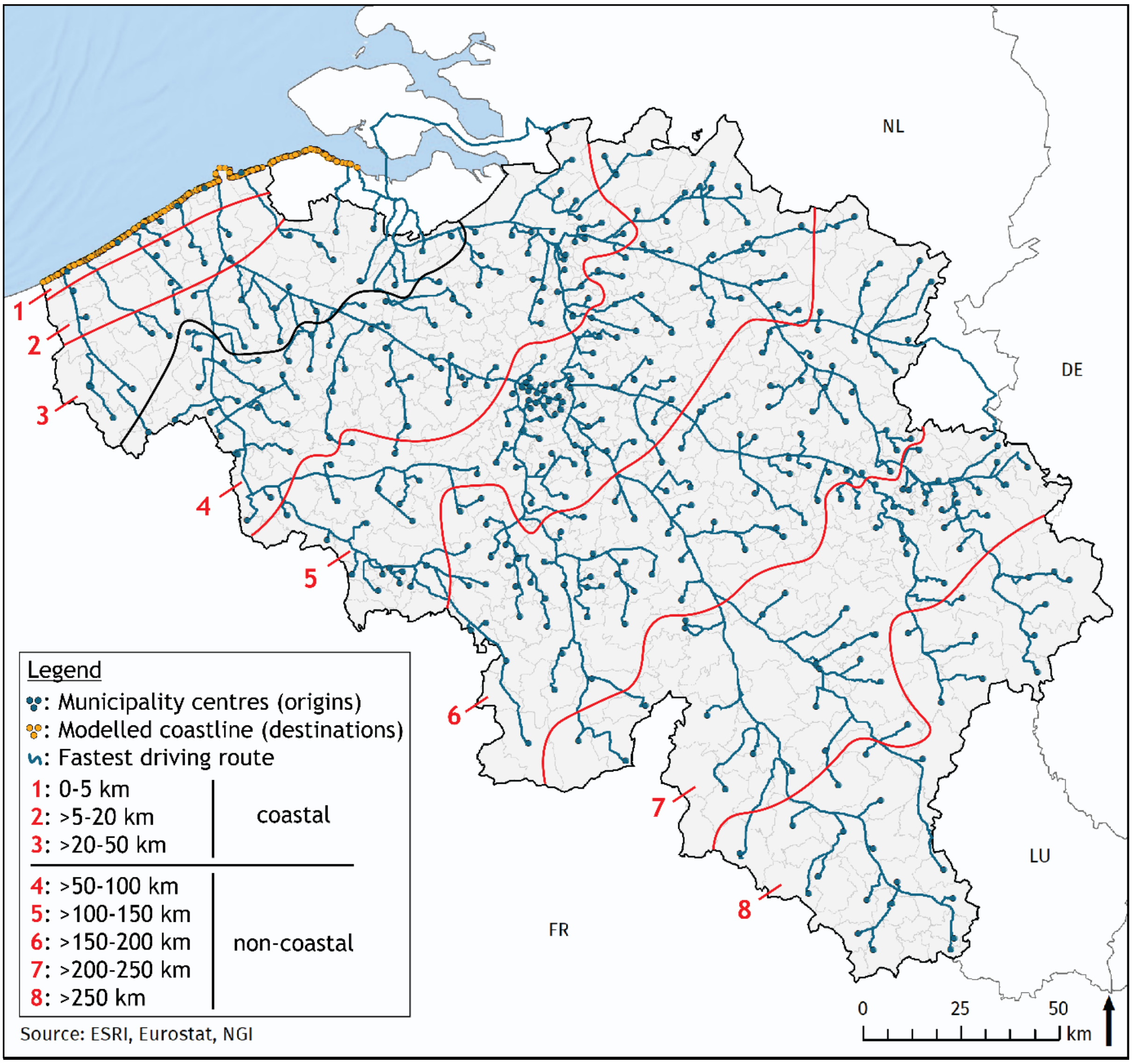


Figure 6: Map of Belgium showing the geographical centers of all sampled municipalities (blue dots, legend) in any wave (1997, 2001, 2004, 2008 and 2013) throughout the study period, and the corresponding fastest driving route to the nearest point at the coast (blue lines, legend). The corresponding distances are categorized as coastal or inland (black line, legend) by the EU NUTS3 definition, or in eight nuanced populations with different residential proximity to the coast (red lines and numbers, legend).

Residential proximity to the coast was then categorized in two ways. The first approach was based on the simple EU Nomenclature of territorial units for statistics (NUTS) definition NUTS3 (European Commission, 2003). This compared the self-reported general health of Belgian residents living in 'inland' areas (i.e., > 50 km = *ref*) to the self-reported general health of people living in 'coastal' areas (i.e., < 50 km). The second approach was more nuanced, where the self-reported general health of residents was compared between eight populations living at finer gradation of coastal proximity, i.e., at 0-5 km, >5-20 km, >20-50 km, >50-100 km = *ref*, >100-150 km, >150-200 km, >200-250 km and >250 km (maximum fastest driving distance is 309.73 km). See Figure 6 for a graphical representation. The specific categories (and reference categories) have been used and adjusted from similar research in England (Wheeler et al., 2012; White, Alcock, et al., 2013). In England, Wheeler et al. (2012) made a differentiation between 0-1 km, >1-5 km, >5-20 km, >20-50 km and > 50 km (*ref*) from the coast, while White et al. (2013a) distinguished 0-5 km, >5-50 km (*ref*) and > 50 km from the coast. The eight categories in this study as such allow comparison with this previous body of work, adjusted for the different geography of Belgium. The reference category in the second approach was defined at >50-100 km because (1) this group makes it most comparable to previous research in England, (2) this group is among the groups that contain the most amount of data, and (3) this group is among the groups that are most representative for the entire country, and does not contain the rather 'remote' populations at the coast or in the Ardennes areas or disproportionally densely populated areas in and around the capital Brussels.

2.1.4. Covariates

Factors that can covary with self-reported general health and residential proximity to the coast were also included in all analyses. Based on expert knowledge and knowledge from literature (Dormann et al., 2013; Wheeler et al., 2012; White, Alcock, et al., 2013), twelve potential confounding factors were selected *a priori*. The first set of potential confounders originated from the HIS survey itself: age (< 20 year, 21-45 year = *ref*, 46-65 year, >65 year), sex (male = *ref*, female), having a chronic disease (yes, no = *ref*, no answer), BMI (normal weight = *ref*, underweight, obesity class I, obesity class II, obesity class III), employment status (employed = *ref*, unemployed), income (quintile 1, quintile 2, quintile 3, quintile 4, quintile 5 = *ref*, no answer), smoking status (non-smoker = *ref*, occasional smoker, daily smoker, no answer) and level of urbanization (urban = *ref*, sub-urban, rural). The year (1997, 2001, 2004 = *ref*, 2008, 2013) and season (winter = *ref*, spring, summer, fall) were also included as potential covariates.

The distinct geographical landscape of Belgium, with for example more forested areas in the southeast (far from the coast), was also considered in the analyses, because an emerging literature is showing that green space or blue space in the neighborhood can influence self-reported general health (Dzhambov et al., 2018; Gascon et al., 2017; Jolando Maas et al., 2006). Accordingly, environmental information from Statbel (2019) was used to complement the first set of covariates with the amount of green space and freshwater blue space in the municipality. The green space ratio (0-10%, >10-20%, >20-30% = *ref*, …, >80-90%, >90-100%) was calculated as the percentage of green outdoor surface area selected from a list of land uses as defined in the municipality cadaster, i.e., grasslands, gardens and parks, forests, savage grounds/disused areas, recreational areas and areas for sports (built areas, roads and agricultural land were not included). Similarly, the freshwater blue space ratio (0-0.25% = *ref*, >0.25-0.5%, >0.5-0.75%, …, >1.75-2%, >2%) was derived from the amount of cadastrated freshwater surface in the municipality, including rivers, lakes, ponds, canals, etc. (not seas).

A prerequisite to act as covariate is that the abovementioned variables change with proximity to the coast. Sex and season were similar across the study area, and were consequently excluded from further analysis (Figure S 4). A description of all variables considered in this study is available in Table S 1.

2.1.5. Hypothesized mechanisms

The hypothesized mechanistic effects of mental health, physical activity, social interactions, and air pollution were also investigated. Mental health was investigated by consulting the General Health Questionnaire (GHQ-12) score, which was also embedded in the HIS, and which measures psychological distress (Goldberg, 1972). This score is calculated on the basis of twelve questions related to for example being able to concentrate, feelings of worry, self-confidence and happiness. Answers were '*More so than usual*', '*Same as usual*', '*Less than usual*', or '*Much less than usual*'. Each answer was coded with a value of 0 (no mental distress) or 1 (mental distress) and summed to an overall (reversed) score of mental health, ranging from 0 (worst mental health) to 12 (best mental health).

Mean health-enhancing energy expenditure linked to physical activity per week was used as a proxy for the level of physical activity, and was also queried through the HIS. This score is based on the International Physical Activity Questionnaire (IPAQ, Craig et al., 2003) and uses energy requirements defined in METs (multiples of the resting metabolic rate) in combination with the time that is spent walking (3.3 METs), performing moderate intensity activities (4.0 METs, e.g., cycling) and vigorous intensity activities (8.0 METs, e.g., running), to calculate a final score in METs per minute (per week).

The quality of social interactions was operationalized by asking participants to rate their appreciation of social interactions as '*really satisfying*' (scored 3), '*rather satisfying*' (scored 2), '*rather unsatisfying*' (scored 1) or '*really unsatisfying*' (scored 0), henceforth referred to as 'social appreciation'. Numerical scores were used during data analysis.

Finally, air pollution levels were assessed using data from the Belgian Interregional Environment Agency (IRCEL - CELINE, 2019) on the annual mean PM_{10} concentration (µg/m³) per municipality. These means per municipality are obtained from interpolated concentrations that are based on several measurement stations all over Belgium. The annual mean PM_{10} concentrations per municipality are considered to be representative for how much each participant was exposed to air pollution in and around his/her residence. Particulate matter correlates well with other anthropogenic air pollutants such as SO_2 and O_3 in Belgian households (Stranger et al., 2009).

2.2. Analyses

The first aim of this study tackled self-reported general health in relation to residential proximity to the coast by formulating linear regression models in R (R Core Team, 2018). Self-reported general health was treated as a numerical scale, as was also done in White et al. (2013a), and because it makes little difference whether analyses assume a linear or ordinal structure for such kinds of measures with limited scores (Ferrer-i-Carbonell & Frijters, 2004). During modelling, the survey design in terms of weights, stratification and clustering was taken into account using the R package 'survey' (Lumley, 2004, 2017). The association between health outcomes and residential proximity to the coast was evaluated by two models, one using the EU NUTS3 definition of 'coastal', and one using eight categories of residential proximity to the coast. In both models, residential proximity to the coast was the main predictor. Then, covariates were added one after the other using a forward selection procedure, in which the covariate that resulted in the highest reduction in Akaike Information Criterion (AIC, lower values indicate a better balance between model fit and model complexity; Zuur et al. 2009) was added next. As such, only variables which explained sufficient information were included. Models were based on respondent data for which no missing values were present for all the variables in the model. Described model coefficients represent the predicted deviation in the response (i.e., self-reported general health) for a category level change from the reference level in the specific predictor, given that all other predictors are held constant. A significance level of 5% was adopted using p-value estimation.

The second aim of this study was to explore the mediating effect of the hypothesized mechanisms, i.e., mental health, physical activity, social appreciation and air pollution. The hypothesized mechanisms are primarily relevant for dwellers relatively close to the coast, so these analyses contrasted only the population living at 0-5 km compared all populations living beyond 5 km from the coast. Mediation effects were quantified by formulating several linear regression models to calculate the total effect, direct effects and indirect effects (Preacher, 2015). These models controlled for the same covariates and used the same forward selection procedure based on the highest reduction in AIC as in the first part of this study. Then, as endorsed by MacKinnon et al. (2004) and Preacher (2015), sample distributions of total, direct and indirect effects were generated by bootstrapping with 16000 random subsamples of the data. In a final stage, percentile 95% confidence intervals were calculated from these distributions to assess deviation from zero and significance. Figure 7 demonstrates the conceptual diagram underlying these mediation models. Indirect effects were used to determine if mediation occurred or not, and the values for path *a* and path *b* were used to explain the nature of the mechanistic relationship.

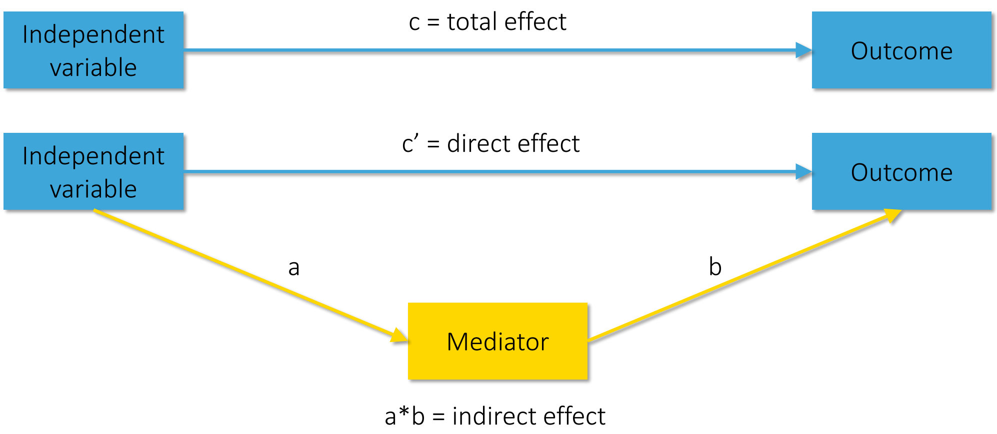


Figure 7: Conceptual diagram of the total effect (c), direct effects (c’) and indirect effects (a*b) calculation. Each arrow represents a linear regression model with predictor of interest at the base of the arrow and outcome at the arrowhead. The letters a, b, c, and c’ indicate regression coefficients and represent either the slope (in the case of a continuous predictor, b) or difference (in the case of a categorical predictor, a, c and c’) in the response.

3. Results

3.1. Self-reported general health - residential proximity to the coast

Self-reported general health was not associated with residential proximity to the coast for Belgian citizens when comparing coastal vs. inland areas. Populations living within 50 km from the coast reported similar general health as those living beyond 50 km from the coast (B = 0.043, 95% CI = -0.022 - 0.108) (Table 1). In contrast, the more nuanced analysis with eight categories of residential proximity to the coast revealed that self-reported general health was positively associated with residential proximity to the coast. Specifically, populations living within 5 km from the coast reported better general health compared to populations living between 50 and 100 km from the coast (B = 0.13, 95% CI = 0.003 - 0.26). Other populations in Belgium who lived further than 5 km from the coast reported similar general health (Table 1).

In both categorical approaches, results were standardized for 7 covariates, which varied with proximity to the coast, i.e., age, having a chronic disease, BMI, employment status, income, smoking status and year (Figure S 4). Unfortunately, each of these variables had some missing values, and the inclusion of these variables resulted in a substantial data-reduction from 60,939 records to 23,624 records for the modelled health-proximity to the coast relationship. The data-reduction per variable can be consulted in the supplementary materials (Table S 1). The reduction of data in the models was irrespective of age, gender ratio, having a chronic disease, BMI, employment, income, smoking ratio, urbanization ratio, and neighborhood green space and blue space (Figure S 4, Table S 2). Note that the urbanization level, green space ratio and blue space ratio were not included in both models, due to insufficient contribution to AIC.

Table 1: Results of the linear regression analyses from two models testing the relation between self-reported general health and residential proximity to the coast. A first model compared the self-reported general health of inland and coastal populations using the 50 km boundary from the EU NUTS3 definition (column 'Coastal vs. Inland'), another model compared the self-reported general health among eight categories of proximity to the coast (column 'Eight categories'). Coefficients for the covariates are also reported. Significance codes for p-values: *: < 0.05, **: < 0.01, ***: < 0.001.
Abbreviations: B = unstandardized model coefficients, CI = Confidence Interval, N = number of observations associated with each coefficient, ref = reference category, R^2 = ratio explained/unexplained variation, AIC = Akaike Information Criterion.

	Self-reported general health B (95% CI)		
	Coastal vs. Inland	**Eight categories**	**n**
Intercept	2.346 (2.297, 2.394) ***	2.341 (2.289, 2.393) ***	23624
Residential proximity to the coast			
Inland (> 50 km) (ref)	-	-	22211
Coastal (< 50 km)	0.043 (-0.022, 0.108)	-	1413
Residential proximity to the coast			
> 250 km	-	0.018 (-0.020, 0.055)	2074
200-250 km	-	0.010 (-0.032, 0.051)	2419
150-200 km	-	-0.001 (-0.040, 0.039)	5014
100-150 km	-	0.016 (-0.018, 0.050)	8153
50-100 km (ref)	-	-	4551
20-50 km	-	0.065 (-0.006, 0.136)	841
5-20 km	-	-0.055 (-0.122, 0.012)	304
0-5 km	-	0.131 (0.003, 0.259) *	268
Age			
0-20 year	0.110 (0.003, 0.216) *	0.109 (0.002, 0.215) *	223
21-45 year (ref)	-	-	9492
46-65 year	-0.147 (-0.177, -0.118) ***	-0.148 (-0.177, -0.119) ***	8057
> 65 year	-0.268 (-0.320, -0.217) ***	-0.269 (-0.320, -0.218) ***	5852
Having a chronic disease			
No (ref)	-	-	16080
Yes	-0.778 (-0.816, -0.741) ***	-0.777 (-0.815, -0.740) ***	7221
No answer	-0.443 (-0.548, -0.338) ***	-0.444 (-0.549, -0.340) ***	323
BMI			
Normal weight (ref)	-	-	11595
Underweight	-0.164 (-0.237, -0.090) ***	-0.161 (-0.236, -0.086) ***	711

Pre-obesity	-0.069 (-0.096, -0.042) ***	-0.069 (-0.096, -0.042) ***	8054
Obesity class I	-0.175 (-0.220, -0.131) ***	-0.176 (-0.220, -0.132) ***	2481
Obesity class II	-0.312 (-0.390, -0.234) ***	-0.313 (-0.390, -0.235) ***	573
Obesity class II	-0.348 (-0.484, -0.211) ***	-0.345 (-0.481, -0.209) ***	210
Having a paid job			
Yes (ref)	-	-	11997
No	-0.178 (-0.212, -0.144) ***	-0.179 (-0.213, -0.145) ***	11237
No answer	-0.148 (-0.237, -0.058) **	-0.147 (-0.234, -0.060) **	390
Income			
Quintile 1	-0.181 (-0.222, -0.140) ***	-0.180 (-0.221, -0.138) ***	3890
Quintile 2	-0.189 (-0.229, -0.148) ***	-0.186 (-0.226, -0.146) ***	3821
Quintile 3	-0.117 (-0.157, -0.078) ***	-0.116 (-0.155, -0.077) ***	4024
Quintile 4	-0.065 (-0.102, -0.027) ***	-0.063 (-0.100, -0.026) ***	3976
Quintile 5 (ref)	-	-	4439
No answer	-0.054 (-0.102, -0.006) *	-0.054 (-0.101, -0.006) *	3474
Smoking status			
Non-smoker (ref)	-	-	16013
Occasional smoker	-0.094 (-0.151, -0.038) **	-0.094 (-0.150, -0.038) **	1141
Daily smoker	-0.147 (-0.173, -0.121) ***	-0.147 (-0.173, -0.121) ***	5744
No answer	-0.032 (-0.095, 0.031)	-0.032 (-0.095, 0.031)	726
Year			
1997	-	-	0
2001	-0.023 (-0.056, 0.009)	-0.024 (-0.055, 0.007)	7459
2004 (ref)	-	-	7474
2008	0.032 (-0.009, 0.072)	0.030 (-0.011, 0.070)	6116
2013	0.017 (-0.027, 0.060)	0.016 (-0.027, 0.058)	2575
Number of observations	23624	23624	
R^2	0.328	0.328	
AIC	10568	10567	

3.2. Mediation by hypothesized mechanisms

Mediation analyses using bootstrapped confidence intervals could not reveal that any of the hypothesized mechanisms included in this study accounted for the relationship between self-reported general health and residential proximity to the coast (Figure 8). More specifically, scores for the mental health, physical activity and social appreciation were similar when comparing populations living within 5 km and beyond 5 km from the coast

(Figure 8). For example, scores for mental health (GHQ-12) are scaled continuously from 0 to 12, and were on average 0.235 points (a, 95% CI = [-0.192; 0.620], i.e., not significant) higher in the 0-5 km group compared to the reference at >5 km from the coast. Hence, no significant indirect effects related to these three factors were observed (Figure 8). Nevertheless, self-reported general health was positively associated with better mental health, higher levels of physical activity and better social appreciation (Figure 8). For example, when mental health was regressed against self-reported general health and bootstrapped multiple times, the mean slope coefficient was 0.081 (b, 95% CI = [0.075; 0.087]). This positive and significant slope indicates that higher values of mental health were associated with higher values for self-reported general health (similarly for physical activity and social appreciation, Figure 8).

The results for air pollution were different. There was significantly less air pollution within 5 km from the coast compared to all municipalities beyond 5 km from the coast (a = -4.239, 95% CI = [-5.104; -3.393]). However, no significant impact of air pollution on the self-reported general health could be detected (b = 0.003, 95% CI = [-0.001; 0.007]). This resulted in the absence of mediation by air pollution (Figure 8).

Results on these mediation pathways were standardized for the same 7 covariates as in the analysis for the health-proximity to the coast relationship. There was an additional data-reduction during the mediation analyses down to 15,418 records, since incomplete data on the four hypothesized mechanisms (i.e., mental health, physical activity, social appreciation and air pollution) also had to be included in the models.

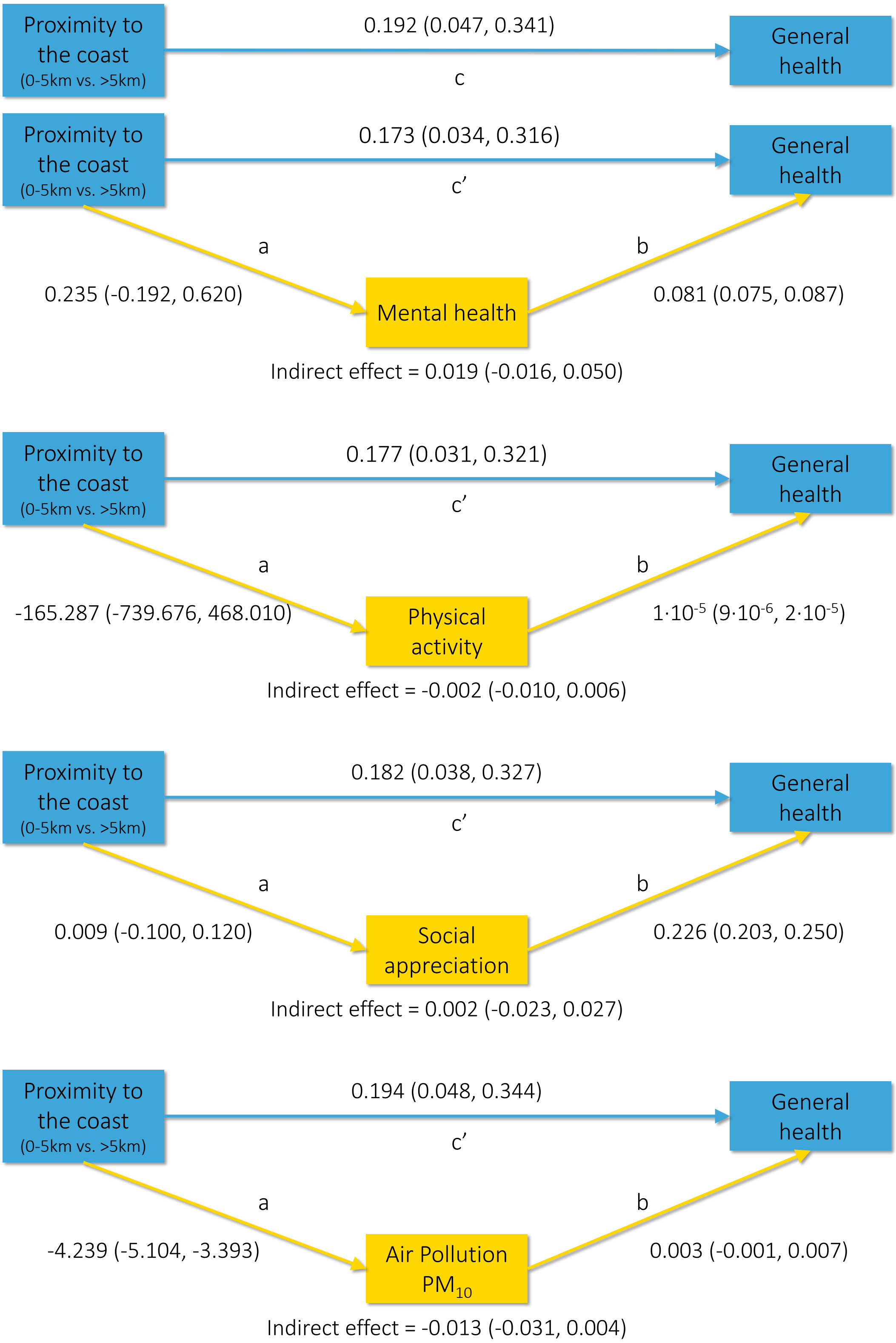


Figure 8: Results of the indirect effect (a*b), direct effect (c’) and total effect (c) calculation for the second approach. Each arrow represents a linear regression model with predictor at the base of the arrow and outcome at the arrowhead. The letters a, b, c, and c’ indicate regression coefficients and represent either the slope (in the case of a continuous predictor, so for b) or difference (in the case of a categorical predictor, so for a, c and c’) in the response.

4. Discussion

This study provides evidence that living at the coast is positively associated with self-reported general health in Belgium. Using data from the Belgian Health Interview Survey, this study found that people residing at less than 5 km from the Belgian coast report better health compared to citizens from further inland. These results are analogous to the results from a cross sectional study from England. More specifically, Wheeler et al. (2012) reported increased self-reported ‘good’ health in urban areas at 0-5 km from the coast compared to inland urban areas (> 50 km). A subsequent analysis on longitudinal data from the same individuals over time, found that people’s health tended to be slightly better in years when they lived nearer the coast (0-5 km) when contrasted to those living further inland (>5-50 km, White et al., 2013a). Thus, this study strengthens the current evidence that living nearer the coast is associated with better health, by revealing new evidence in the different national context of Belgium.

Scientists have been proposing several mechanisms to explain why people living near the coast report better health and well-being. This study assessed the four most commonly hypothesized mechanisms to explain better health in coastal areas, i.e., less stress and better mental health (Dempsey et al., 2018; Garrett, White, et al., 2019; Nutsford et al., 2016), more physical activity (Elliott et al., 2015, 2018; White, Wheeler, et al., 2014), better appreciation of social interactions (S. L. Bell et al., 2015; Dzhambov et al., 2018) and better environmental quality such as less air pollution (Ashbullby et al., 2013; S. L. Bell et al., 2015; Davidson et al., 2005; Dempsey et al., 2018; Elliott et al., 2018; Kerr et al., 2014; Pasanen et al., 2019; Pope & Dockery, 2006; Prüss-Ustün et al., 2017; White, Pahl, et al., 2013). However, this study found no evidence that any of the above-stated mechanisms accounted for the relationship between health and residential proximity to the coast for Belgian citizens. No such indirect effects were observed because the scores for mental health, physical activity and social appreciation were similar for people living within and beyond 5 km from the coast. This contrasts with the findings from literature from other countries (Ashbullby et al., 2013; S. L. Bell et al., 2015; Dempsey et al., 2018; Elliott et al., 2018; Kerr et al., 2014; Pasanen et al., 2019; White, Pahl, et al., 2013). It is argued that the unexpected absence of any mediation effects in this study may be the result of the spatial heterogeneous character of the Belgian coast. The abovementioned cited literature mostly focused on the effects of exposure to beaches or seeing the seawater per se (e.g., Ashbullby et al., 2013; Dempsey et al., 2018). However, the Belgian coast displays a mosaic pattern of urban, rural, and natural areas, similar as other coastlines in Europe. As such, the health benefits from the sea per se can become obscured by being exposed to other types of environments. In Belgium for example, sandy beaches co-occur next to dunes, agricultural land and nature parks, which are hypothesized to have positive impacts on the mental health, physical activity and social interactions. In contrast, coastal towns, cities and harbors are hypothesized to have negative impacts on these mechanisms. It remains to be investigated how exposure to a combination of such different coastal environments on a small spatial scale can impact the mental health and the physical and social activities performed around the residence, and how such processes may have resulted in the observed better overall health at the Belgian coast.

Regarding air pollution, this study found lower PM_{10} concentrations within 5 km from the coast compared to the average concentrations in other parts of Belgium. Very few modern studies compared levels of air pollution between coastal and inland areas, but our results for example resemble the lower PM_{10} concentrations found in coastal zones of California compared to inland areas in California (B. M. Kim et al., 2000). The results of this study are also consistent with the well-established historical belief that coastal air is healthier than inland air (Charlier & Chaineux, 2009; Pirlet, 2016; Verkest, 1898). Indeed, already since the mid-nineteenth century, the air in coastal areas was advertised to be health promoting by the still-famous Flemish writer, Hendrik Conscience (1861), for example. He wrote "the sea air is healthy and gives strength to ill persons" (translated from the original Dutch version) and his statements are known to have reached a wide public all over Belgium. Although this study did not provide evidence that reduced air pollution was responsible for the better health of Belgian coastal residents, it is generally accepted that air pollution negatively impacts public health by a range of adverse health outcomes, such as increased prevalence of cardiopulmonary conditions and subsequent mortality (Pope & Dockery, 2006; Pope III, 2002). An important nuance that has to be made here is that the absence of land is not the only factor which can influence the air quality in coastal areas. Marine traffic (e.g., in harbors) and harmful algal blooms can for example also impact the healthiness of the air with measurable differences in coastal areas (Fleming et al., 2011; Van Acker et al., 2020; Viana et al., 2014).

None of the hypothesized mechanisms were shown to account for the health benefits at the Belgian coast. Systematic reviews also suggests that mechanistic relations between health and natural environments are entangled and yet unclear (Dzhambov et al., 2018; Gascon et al., 2017). It is also likely that several mechanisms interact and have additive and/or synergistic effects on overall health. Therefore, a more thorough investigation of these hypothesized mechanisms is needed to unravel which mixture of factors is actually driving better health in coastal populations, while considering the heterogeneity of coastal areas. That recent related studies investigated the health inequalities among populations with different socio-economic indices is encouraged (Boyd et al., 2018; Garrett, Clitherow, et al., 2019). However, the observed better self-reported general health in coastal areas in this study persisted even after standardizing for a whole range of socio-economic, demographic and lifestyle factors. Therefore, also relatively unexplored plausible pathways should be considered as well, for example (1) the potential presence of biogenic compounds in coastal sea spray which can inhibit molecular pathways that are linked to cancer and high levels of cholesterol (Asselman et al., 2019); and (2) the promotion of seafood consumption, for example as promoted by the numerous coastal town restaurants, which may impact health in multiple ways (McManus et al., 2011). Furthermore, scientists still don't know how to isolate the amount of health benefits that are derived from the sea per se. To unravel these marine influences from other factors which can influence health, future research should try to encompass all environmental exposures, i.e., those that complement the universal genomic differences between individuals ('exposome', Miller, 2014; Vrijheid, 2014; Wild, 2012). If one wants to incorporate this exposome paradigm in coastal and other exposure assessments, researchers will need to integrate interdisciplinary innovation-driven research into the existing traditional methods.

This paper provides positive associations between the ocean and human health, and calls to policy makers to assure the coastal salutogenic resources in the future for continued public use. Policy-makers are encouraged to consider the health benefits that are associated with living near the coast. However, policy-makers should consider the accessibility of these benefits for all socio-economic classes in society. Research learns us for example that seeing the sea can be especially relevant for coastal residents (Dempsey et al., 2018; Nutsford et al., 2016), but that for example having a sea-view is also reflected in real estate prices (E. Lange & Schaeffer, 2001). As such, this study answers and contributes to the call for action for sustainable use of our ocean, seas and marine resources for sustainable development (Fleming et al., 2019; UN Secretary General, 2017). In this respect, linking Sustainable Development Goal (SDG) 3 on human health with SDG 14 on oceanic and marine resources will require joint effort and collaboration of environmental researchers and clinicians (Depledge et al., 2019). Targeting specific health outcomes that can be translated in monetary values will be most relevant for the landscape decision-making processes (e.g., physical activity and quality-adjusted life years – QALYs in Papathanasopoulou et al., 2016; White et al., 2016a).

4.1. Limitations

This study's findings are based on large representative samples of the Belgian population over several years and robust methods were used not only to test the direct association between self-reported general health and residential proximity to the coast, but also to explore the mediation effects by hypothesized mechanisms. This study additionnally included a lot of demographic, health behavior, lifestyle, and environmental covariates, many of which were not included in similar previous research. This resulted in substantial data reduction, which was not age, sex or income specific. This study did not incorporate data on the frequency and type of coastal visits to assess intentional contact with the coast. This could have provided additional information that could potentially explain the absence of any of the mediaton effects, and may have provided usefull suggestions for other mechanisms at play. Additionnally, the present study did not test for the combined effects of multiple hypothesized mechanisms. Doing so may be possible using emerging pan-European survey evidence of the effect of blue spaces on public health (i.e., from the H2020 BlueHealth project, Grellier et al., (2017)). Finally, the ability to draw conclusions is still limited by the repeat cross-sectional design of the survey. For example, it is not possible to exclude potential selection effects which may have arisen because more healthy (and more wealthy) people tend to choose to live in coastal areas ('healthy migrant effect', Wheeler et al., 2012).

5. Conclusion

In conclusion, by analyzing a cross-sectional national health survey of the Belgian population, this study found that living in proximity to the coast is associated with better self-reported general health. People who reside at the coast (i.e., at 0-5 km) reported better general health, but this was not mediated by mental health, physical activity, appreciation of social interactions and air pollution. The absence of any mediation effects may be caused by the spatial heterogeneity of the Belgian coast, or the presence of alternative unexplored mechanisms. The positive associations between the ocean and human health observed in this study encourage policy makers to manage coastal seas sustainably to maintain continued public use of its salutogenic resources throughout the future.

6. Acknowledgements

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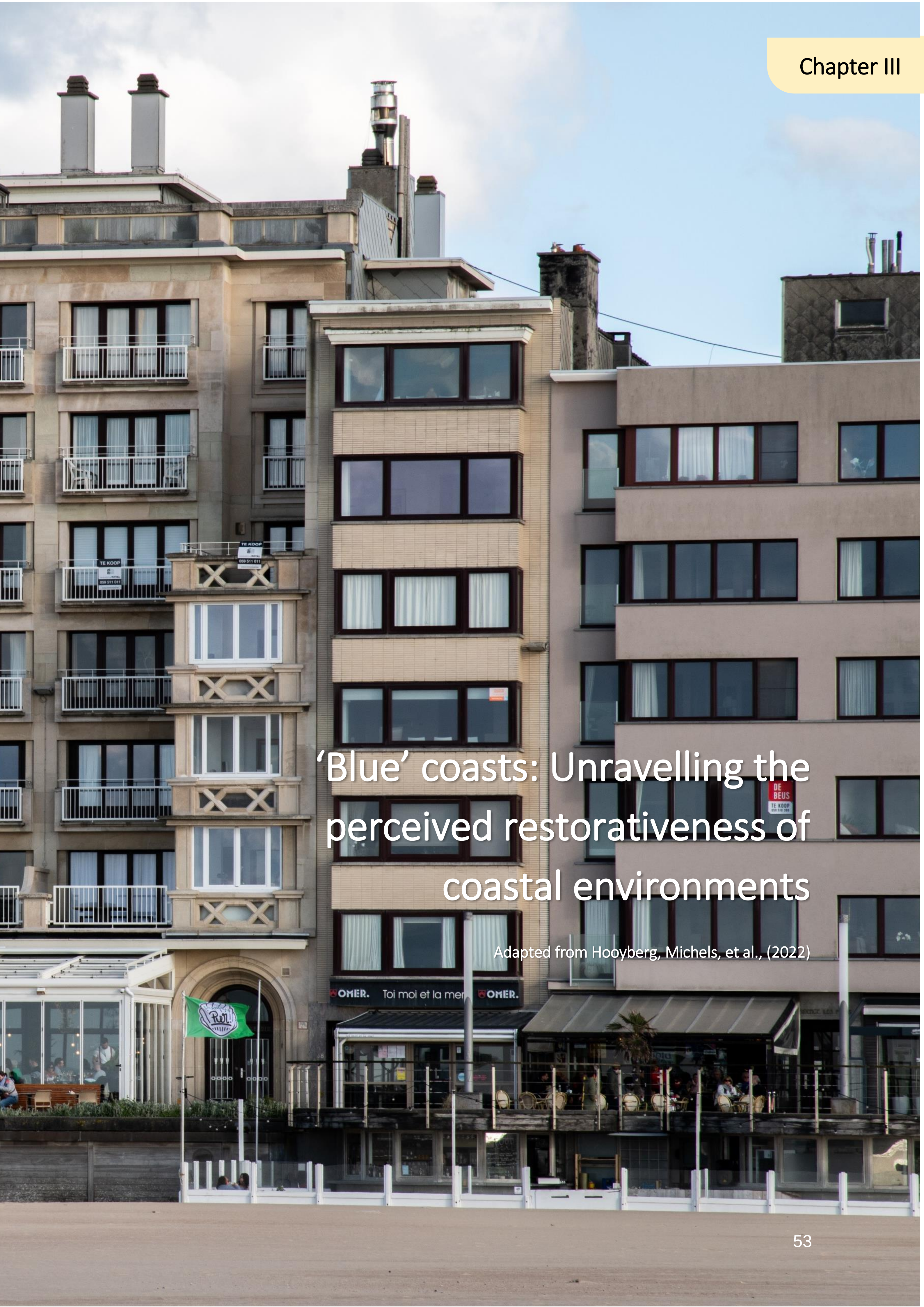


‘Blue’ coasts: Unravelling the perceived restorativeness of coastal environments

Adapted from Hooyberg, Michels, et al., (2022)

Abstract

Outdoor environments benefit health by providing psychological restoration, but the degree of psychological restoration may vary considerably within heterogenous areas. This study focused on the Belgian coast to quantify the inter- and intra-environment variation in psychological restoration and the influence of natural and urban components and people. Students (N = 102, 18-30y, 83% female) rated 52 pictures of ten coastal environments and five beach-specific locations on a five-item perceived restorativeness scale (PRS) in random order. General linear mixed modelling standardized for individual and study design-related covariates and random effects. Generally, the average PRS-scores varied according to the scenes' 'naturalness'. The PRS was up to 30% higher for beaches, dunes, and salt marshes (PRS ≈ 8/10) than for dikes, docks, recreational harbors, and towns (PRS ≈ 5/10). Green parks, piers, and historical sites scored intermediate. At the beach specifically, pictures taken 'on a breakwater' (PRS ≈ 8.5/10) scored up to 20% higher than those taken 'in a beach bar' and 'between beach cabins' (PRS ≈ 6.5/10). The PRS was also associated with the relative surface area of the picture-components. Associations were positive for natural components (i.e., vegetation, sky, and natural underground, not water), negative for urban components (i.e., buildings, vehicles and hardened underground), and unclear for people. This study confirmed the hypothesized inter- and intra-environment variation in the psychological restoration along the Belgian coast, and highlighted the importance of coastal nature for mental health. The generated insights can lead to better informed policy decisions to maximize the health benefits offered by coastal environments.

Keywords

Urban nature, Coastal environment, Attention restoration, Health benefits, Picture components, People

1. Introduction

Understanding how outdoor environments impact psychological restoration is key for achieving and maintaining good mental health in our society (Filipova et al., 2020). Poor mental health has become increasingly prevalent, and now approximately one out of six people suffer from mental illness in Europe (OECD & European Commission, 2020). To cost-effectively treat and prevent poor mental health, researchers have increasingly investigated how outdoor environments may act as "the ultimate healthcare system" (UNEP, 2019).

Outdoor environments can provide psychological restoration in many ways, but it is still unclear which physical and social components of the environment determine its restorativeness. Exposure to outdoor environments can bring psychological restoration by replenishing cognitive resources (Berman et al., 2012; Grassini et al., 2019; Ladouce et al., 2019; Ohly et al., 2016; Stevenson et al., 2018), inducing a more positive emotional balance (Bratman et al., 2021; Brooks et al., 2017; Browning, Shipley, et al., 2020; Kondo, Triguero-Mas, et al., 2020), and/or altering the hormonal and nervous system-related physiology towards less stress (Haluza et al., 2014; Hartig et al., 2014; Mygind, Kjeldsted, Hartmeyer, Mygind, Stevenson, et al., 2019). Attention restoration theory predicts that the restorativeness of an environment increases when there is high (soft) fascination, scope/extent, compatibility, and being away, because these features allow a person to be distracted from everyday demands and to replenish depleted directed attention resources (R. Kaplan & Kaplan, 1989; S. Kaplan, 1995). On the other hand, psycho-evolutionary theory explains that humans have evolved to recover quickly from psychological and physiological stress in natural non-threatening and resource-rich environments, and not in urban environments (Ulrich, 1981, 1983; Ulrich et al., 1991). A large body of literature has shown that components that increase or decrease the naturalness (e.g., vegetation, urban park attributes) indeed co-determine the environment's potential for psychological restoration (Gascon et al., 2015; Georgiou et al., 2021; Jiang et al., 2014, 2015, 2016; Karmanov & Hamel, 2008; Labib et al., 2020a; Lindal & Hartig, 2013, 2015; Liu et al., 2022; Mears et al., 2019; Neilson et al., 2016, 2017, 2020; T. Nguyen et al., 2018; Nordh et al., 2009; Van den Berg et al., 2014; White et al., 2010; White, Pahl, et al., 2016). Together with the natural and urban components, the presence of other people may also alter the potential for psychological restoration in an environment (Collado et al., 2017; Jolanda Maas et al., 2009; Neale et al., 2021; Staats & Hartig, 2004). The few studies that investigated this showed that psychological restoration is likely to be increased in the presence of non-threatening people (e.g., friends or family) without overcrowding, due to increased perceived safety (Ashbullby et al., 2013; Herzog & Rector, 2009; Nordh et al., 2011; Staats & Hartig, 2004). However, there exist many types of environments with different proportions of natural and urban components and people, such as along urbanized coasts. It is still unknown how the psychological restoration varies within such heterogeneous environments, and how each component of the environment contributes to forming the restorative experience (Browning et al., 2021; Hartig et al., 2014; Joye & de

Block, 2011; Neilson et al., 2019; Ohly et al., 2016; Stevenson et al., 2018; Velarde et al., 2007).

Previous research has illustrated that coastal areas as a whole are beneficial for human health (Hooyberg et al., 2020; Peng et al., 2016b; Wheeler et al., 2012; White, Alcock, et al., 2013), that there is some level of cross-country variation in Europe (White et al., 2021)(White et al., 2021), that the influence of coastal areas as a whole on psychological restoration and mental health is yet unclear (Gascon et al., 2015, 2017; Hooyberg et al., 2020), but that beaches alone definitely promote psychological restoration (Hipp & Ogunseitan, 2011; Jarratt & Gammon, 2016; Peng et al., 2016b; Wyles et al., 2016), and that two adjacent types of coastal environments can have different impacts on restoration (i.e., urbanized beach vs. coastal city; (Vert et al., 2020). However, the heterogeneity in the restorativeness due to the spatial diversity in the types of coastal environments and their components has not been addressed. For example, at the Belgian coast, more natural environments (e.g., beaches, dunes, salt marshes) are interspersed with more urban ones (e.g., towns, dikes, harbors), and this inter-environment variability may explain why living at the Belgian coast is associated with overall no improvements in psychological health (Hooyberg et al., 2020). Moreover, Vert and colleagues (2020) illustrated that walking in a nearby urban beach brought more restoration compared to walking in a nearby coastal city, which further supports the hypothesis that there is inter-environment variation in psychological restoration along coastal areas. Additionally, intra-environment variation may also exist within a coastal environment, especially at beaches. The presence or absence of various anthropogenic amenities, such as beach bars or beach cabins, may cause micro-scale differences in the potential for psychological restoration. Previous studies have inexplicitly supported this notion by describing the varying experiences of visitors depending on the varying natural and urban components and people at beaches (Ashbullby et al., 2013; Chen & Teng, 2016; Maguire et al., 2011; Subiza-Pérez et al., 2020). Thus, both inter- and intra-environment variation in the restorativeness of coastal areas may have resulted in inconsistent findings across studies, but it is still unclear how (de Vries et al., 2021; Gascon et al., 2017; Georgiou et al., 2021; Severin et al., 2021; Vert et al., 2020; White et al., 2010; White, Pahl, et al., 2017).

This study's first aim was to quantify the inter- and intra-environment variation in psychological restoration along the Belgian coast. The second aim was to quantify the influence of naturally varying doses of natural and urban components and people in the environments on the psychological restoration. To do so, ten distinctive coastal environments and five distinctive beach environments were identified along the Belgian coast and represented by pictures, which were to be rated by the study participants on the perceived restorativeness. The picture-ratings were linked to the type of coastal or beach environment, and to the doses of the natural and urban components and people as identified on the pictures.

2. Materials and methods

2.1. Study design

This study's aims were addressed with data from a picture-rating study with a within-subject design. The pictures showed ten coastal environments and five beach environments along the Belgian coast, and each participant rated each picture on the perceived restorativeness of the displayed environment in a randomized order. The pictures were also used to quantify the doses of natural and urban components and of people, to be representative for their doses in the real environments. The experiment was designed to answer additional research questions than those addressed in this study, and here we only report those aspects that were relevant to address this study's aims.

Tackling the aims of this study with a picture-rating study required to address three methodological challenges. Firstly, pictures only represent the visual part of the actual multi-exposure environment, and the components of the real environment are only being represented by their visual aspects on the pictures (Browning et al., 2021). Secondly, the ratings of the perceived restorativeness only represents how the participant perceived the depicted environments to be restorative, and thus differs from objective measures for psychological restoration (Figure 9; Hartig et al., 2014, 1997). Thirdly, the participant's attention and conduct towards the visualized environment may differ between participants and may change throughout the experiment. More specifically, experimentally induced fatigue-effects or other unconscious visual and attentional processes (e.g., concentration, gaze) may alter the actual dose of the exposure and its according effect sizes (Nordh et al., 2010). In turn, this can be influenced by individual or contextual effect modifiers (e.g., mental health; White et al., 2020). These three methodological challenges seem to have hardly been reported in the literature (Browning et al., 2021). Therefore, we present them here in a newly developed diagram (Figure 9). To address these challenges, we thoroughly searched the extant literature to find the best methodological practices. Many good practices have been reported (Hartig et al., 1997, 2014; Jiang et al., 2014, 2015, 2016; Nordh et al., 2009; White et al., 2010), but no standardized guidelines or best methodological practices seemed to be available (Browning et al., 2021). Therefore, we built further on the studies that reported good practices, and tackled the three challenges by assembling a valid picture set, an improved scale for perceived restorativeness, and a good experimental procedure. Recently, this strategy was also suggested by the review of Browning and colleagues (2021).

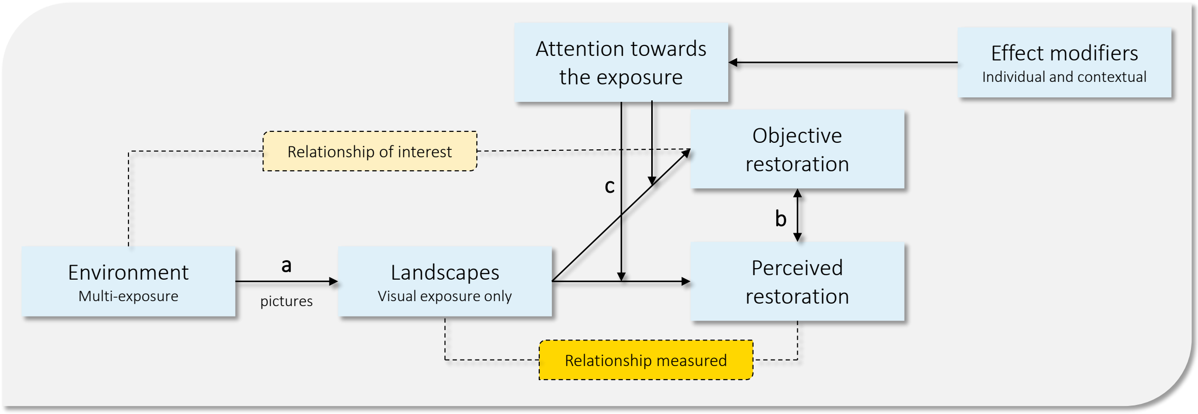


Figure 9: Methodological challenges in picture-rating studies. The validity of the measured relation (gold) for the relation of interest (light yellow) depends on the representability of the pictures for the real multi-exposure environment (a), the accuracy of the participants' perceived restoration for the objective restoration (b), and visual-attentional processes that are in turn influenced by individual and contextual effect modifiers (c; White et al 2020).

2.2. Participants

The study participants included 102 healthy 18-to-29-year-old students (Table 2). This sample size was in line with an a priori power analysis based on similar work by Nordh et al. (2009) and White et al. (2010). No exclusion criteria were adopted. The data-collection occurred in two periods from February 21st till March 12th 2020 (labelled as 'Period 1') and from September 7th till November 27th 2020 (labeled as 'Period 2'), due to the restricted government regulations to combat the spread of the COVID-19 virus. The study was conducted in accordance with The Code of Ethics of the World Medical Association for experiments involving humans (Declaration of Helsinki) and was approved by Ghent University's Medical Ethical Committee.

Table 2: Participants' characteristics table. Summary of all participant-related covariates, indicated for categorical variables as the number (N) of participants in each factor level, or for continuous variables as the mean (M) with standard deviation (SD). Detailed reasoning and implementation of scoring methods are available in supplementary materials section 2.1.1.
Abbreviations and references to scales: BMI = Body Mass Index; METs = Metabolic Equivalents; NR = Nature Relatedness (Nisbet & Zelenski, 2013); SOC = Sense of Coherence (Jellesma et al., 2006; Luyckx et al., 2012); PSS = Perceived Stress Scale (van der Ploeg, 2013); BAT = Burnout Assessment Tool (Schaufeli et al., 2019); PTQ-t = Perseverance Thinking Questionnaire – trait version (Ehring et al., 2012).

Participants' characteristics (factor levels) [units]	**N per factor level, or M (SD)**
Age (18-20y, 21-23y, 24-29y)	41, 39, 22
Gender (male, female)	17, 85
Socio-economic status (very good, good, neutral-or-bad)	5, 55, 42
Smoking status (non-smoker, (former) smoker)	96, 6
Diet (normal-or-special diets, no meat)	85, 17
BMI [kg/m²]	21.93 (3.11)
Physical activity [METs/min]	1972.8 (1686.96)
Associating the Belgian coast with obligations (yes, no)	7, 95
Number of visits to the Belgian coast in the past three months [#]	2.41 (5.38)
Number of visits to the Belgian coast in the past year [#]	8.46 (24.94)
Number of visits to the Belgian coast per year as a kid (never, 1-4 x/y, 5-8 x/y, 9-12 x/y, 12-24 x/y, >24 x/y)	7, 49, 15, 11, 9, 11
Dog ownership (yes, no)	22, 80
Near-home urbanization (rural, semi-urban, urban)	38, 49, 15
Near-home access to green spaces (none, few, moderate, a lot)	2, 12, 39, 49
Near-home access to blue spaces (none, few, moderate, a lot)	26, 38, 28, 10
Near-home air quality [rated 0-10]	6.35 (2.3)
Near-home noise levels [rated 0-10]	3.48 (2.39)
Residential coastal proximity (>50km, >20-50km, >5-20km, >1-5km, 0-1km)	74, 18, 5, 3, 2
Satisfaction to residential coastal proximity (good, wants more, wants less)	53, 49, 0
Nature relatedness – 6-item NR scale [1-6]	3.21 (0.82)
Coastal relatedness – 6-item NR scale adapted for coasts [1-6]	2.6 (0.84)
Sense of coherence – 13-item SOC scale [1-5]	2.54 (0.52)
Stress in the past month – 10-item PSS scale [0-4]	1.56 (0.53)
Burnout score – 33-item BAT scale [1-5]	2.27 (0.51)
Rumination – 60-item PTQ-t scale [0-60]	23.48 (11.49)

Sleep quality (never, 1 x/week or less, 2-3 x/week, >4 x/week)	18, 47, 27, 10
State stress [0-10]	2.96 (1.77)
Period of sampling (Period 1, Period 2)	21, 81

2.3. Pictures

2.3.1. Picture-set assembly

The participants watched 52 pictures that were photographed along the Belgian coast. The pictures were optimized to maximally represent the real environments and to be standardized relative to each other.

The Belgian coast is 65 km long and has landward dunes and urban developments in the form of municipalities and harbors (Kustportaal; Marine Regions, 2009), and we targeted leisure destinations approximately < 1 km to the shore. We chose the most commonly found environments along the Belgian coast, and those that are most representative for what coastal visitors may encounter during their recreational activities. As such, ten coastal environments were included in this study for the inter-environment comparison: beaches, piers, dunes, salt marshes, green parks, dikes, towns, recreational harbors, docks, and historical sites; and five beach environments for the intra-environment comparison: open beach, in the seawater, on a breakwater, between beach cabins, and in a beach bar.

A large number of pictures were taken in the environments on June 7th, June 8th, and June 17th 2019 (N = 838), from which a selection was made later. The photography was done by the lead author of this study, who had explored most of the leisure destinations along the Belgian coast in his private life prior to the start of this study. The pictures were taken at multiple locations within the identified environments and in the most likely directions of view, while ensuring that the amount of natural and urban components and people on the pictures were representative for their amounts that are commonly found in the real environments throughout the year. Thus, we did not exclude people but avoided taking pictures during peak-tourism. Similarly as in previous studies, we took all pictures during calm and sunny weather conditions (Jiang et al., 2014 and White et al., 2010). Additionally, since several technical attributes of the pictures could impact the viewers' experience and the pictures' representativeness for the real environment, such as picture sharpness, zoom, and perspective (Yarbus, 1967), the pictures were taken with the appropriate camera settings and shooting practices (supplementary materials section 2.1.2).

The pictures that were shown to the participants and were relevant for addressing this study's aims included 52 of the most representative pictures from the large initial set. The strategy was to eliminate the scenes that contained the least elements or situations that would raise questions among the participants or draw their attention undesirably. In the end, we made sure that each environment was represented by at least two pictures (Table 3). Notably, one picture of a salt marsh needed to be retrieved from the web, and disturbing elements on two-pictures were edited out. All the pictures were further edited to improve the realism of the lightness and darkness (e.g., details visible in the shadows) and to homogenize color tone, saturation, and contrast across the pictures. Editing was done in Adobe Lightroom (Adobe, 2020a) and Adobe Photoshop (Adobe, 2020b), after which all pictures were exported in jpeg-format with a full-HD 1920 x 1080 resolution to be imported in E-Prime 3.0 (Psychology Software Tools Inc., 2016) for visualization during the experimental procedure and in Tobii Pro Lab (Tobii Pro AB, 2014) for analyses of the pictures' components.

Table 3: Tabulated number of pictures per environment and per comparison (inter- or intra-environment). The corresponding pictures can be retrieved from https://doi.org/10.14284/560 (Hooyberg, Everaert, et al., 2022).

		Environments	**$N_{pictures}$**
		Trials	2
Coastal environments (inter-environment comparison)	Beach environments (intra-environment comparison)	Beach/Open beach	6
		In the seawater	2
		On a wave breaker	2
		In a beach bar	2
		Between beach cabins	2
		Dikes	6
		Towns	6
		Recreational harbors	6
		Piers	6
		Dunes	4
		Docks	4
		Salt marshes	2
		Green parks	2
		Historical places	2

2.3.2. Dose of natural and urban components and people

To calculate the dose of natural and urban components and people on each picture, we adopted a pixel-based density calculation. This procedure was similar to the tree density calculations in panoramic exposures by Jiang et al. (2014, 2015, 2016), which were highly appraised by the review of nature simulations by Browning et al. (2021). In this study, each part of each picture that was easily identifiable and distinguishable from other parts of the picture was delineated by manually drawing a polygon around it. We meant to include each pixel to exactly one polygon, so that there was no overlap or unassigned pixels at the borders of the polygons (see Figure 10 for an example). Then, the relative cover of each polygon was calculated as the number of pixels belonging to that polygon divided by the total number of pixels in the picture. As such, the relative cover of a polygon is the result of both the component's size (i.e., bigger things take up more of the picture) and distance to the camera (the further away, the smaller it is on the picture). Consequently, the relative cover of the component that is delineated by one or more polygons can be interpreted as its 'dose'. Subsequently, all the polygons were hierarchically classified according to 52 classes based on the type of component they enclosed (Figure 11). At the highest level, the hierarchy distinguished 'natural' components, 'urban' components, and 'people'. Natural and urban components further harbored 'lower-level constituents'. For example, 'natural' components harbored 'water', which in turn harbored 'freshwater' and 'saltwater'.

For each class in the hierarchy, the relative cover of all the polygons referring to that class at that level and at underlying levels was summed for further analyses. As such, each picture has a percentage of dose (= the summed relative cover) for each type of component in the hierarchy. In each picture, the center area with a coverage of 0.094% (circle) was not considered, because this served other aims than those addressed in this study. The polygons were drawn and classified with Tobii Pro Lab's built-in functions (Tobii Pro AB, 2014), and their relative cover was calculated with the triangle method implemented by the function *polyarea* of the *geometry* package (Habel et al., 2019) in R (R Core Team, 2018).

Figure 10: Illustration of a picture of the dike without (A) and with (B) picture component delineations. Each polygon was given a random color by the software and solely serves illustrative purposes.

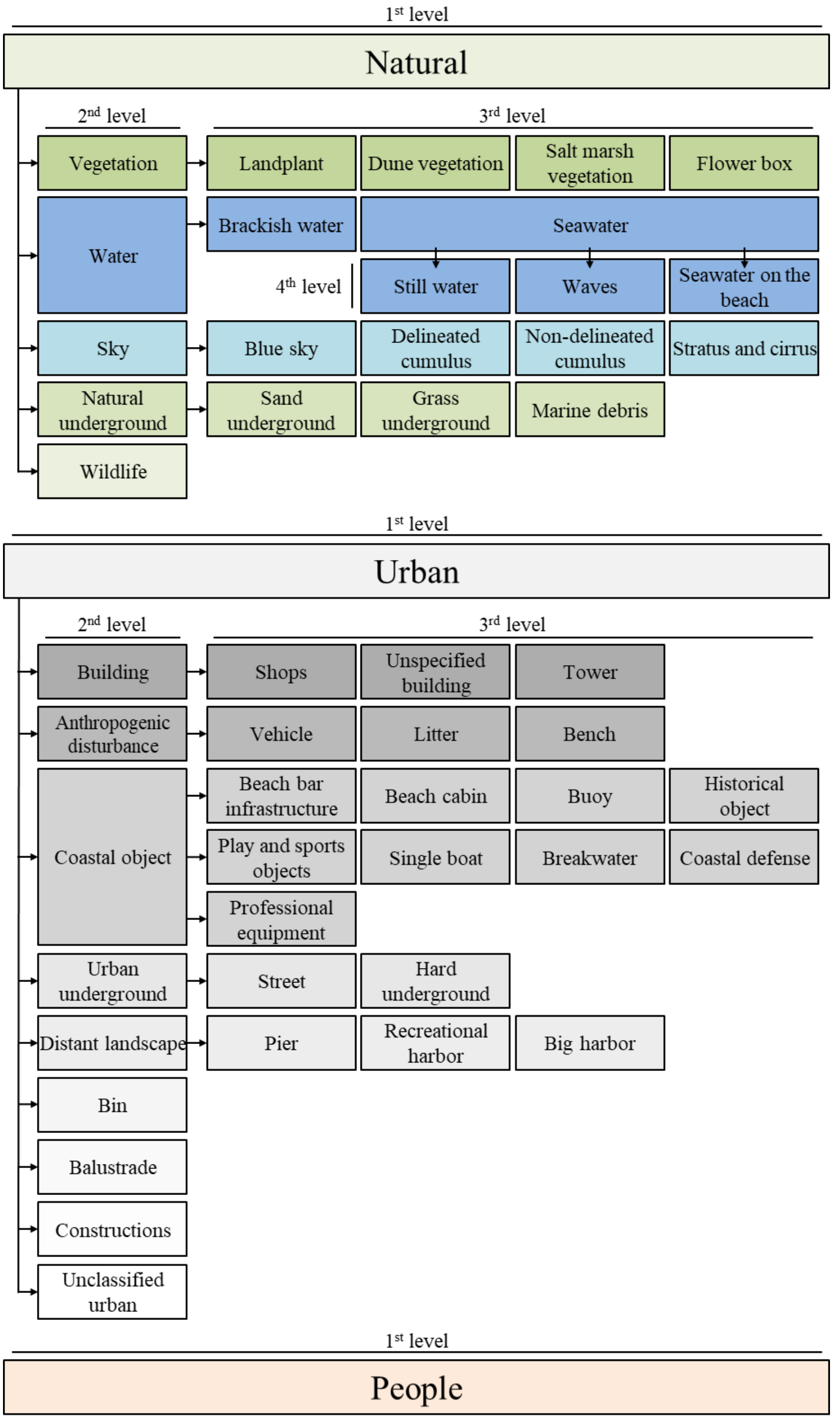


Figure 11: Hierarchical classification of the natural and urban components and people identified on the pictures. Natural and urban components harbor different types of lower-level constituents. Each arrow represents the transition from a higher level to a lower level. The colors of the classes are purely illustrative.

Figure 12 shows that each coastal environment was distinct for the types and proportions of natural and urban components and people (full details available in supplementary materials section 2.1.3). All pictures used in this study and their calculated doses of natural and urban components and people and their lower-level constituents are openly available from https://doi.org/10.14284/560 (Hooyberg, Everaert, et al., 2022).

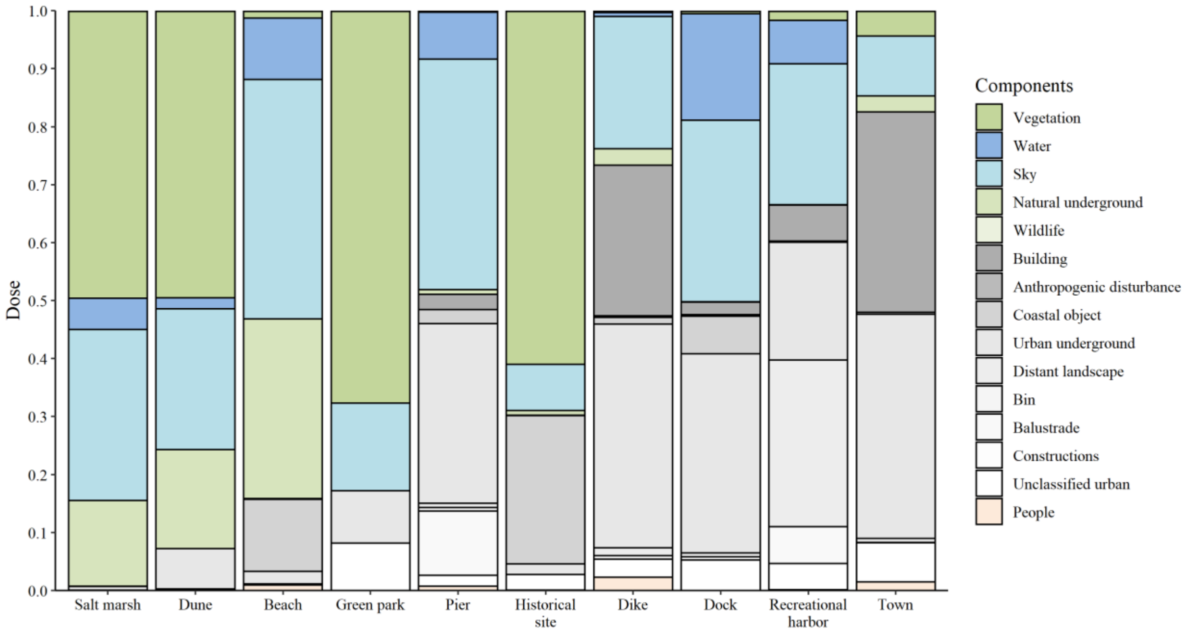


Figure 12: Overview of the dose of natural and urban components and people per coastal environment. The dose of a component is calculated as its relative surface area on each picture, averaged for the pictures per coastal environment. Only the second-level constituents of the natural and urban components are shown for balancing clarity and information. Full details are available in supplementary materials section 2.1.3. The five beach-specific environments also assessed in this study are embedded under 'Beach'. Colors are purely illustrative.

2.4. The picture-rating study

The picture-rating study consisted of online pre-appointment phase and an appointment at the computer lab. The pre-appointment phase aimed to inform the participants about the practicalities and goal of the study (i.e., to assess perceived restorativeness of the coast by a picture-rating study), and to take a first background questionnaire with their digital informed consent. The participants were also instructed not to be under the influence of alcohol, caffeine, or tranquilizing substances on the day of their appointment, and to rest for 10 minutes in the waiting room before their appointment. Upon entry in the computer lab, the participants were briefed and asked for their informed consent before being habituated to the lab. During habituation, they filled in a second questionnaire about their state mental health. Then, the pictures were shown and rated by the participants on a computer. This started with a short on-screen text that gave the following instructions in the participants' native language Dutch. "*Imagine that you have experienced a mentally exhausting period, and that you have come to the Belgian coast to relax. Imagine that you are at the place where each of the following pictures were taken.*" This was similar as was done in previous research (Nordh et al., 2009; White et al., 2010). After two trial pictures, which were the same for every participant, the participants were exposed to the pictures in random order. Each picture was shown for eight seconds, after which there was an unlimited period for participants to rate it. To ensure that the participants' focus was on the center of the screen before the next picture was shown, an eye-tracking-controlled centered fixation cross was displayed before each picture was shown (the eye-tracker was calibrated with 9 fixations points during the habituation to the lab). The fixation cross was shown for 850 milliseconds and an additional minimum 150 milliseconds during which the participant had to lock focus on the cross. To avoid mental exhaustion during the course of the experiment, a two-minute recovery period was included after half the pictures were rated. A grey screen with text instructed the participants to rest comfortably. After all the pictures were rated, the participants were debriefed and compensated financially (€15) for their efforts. The computer-based procedure was programmed in E-Prime 3.0 (Psychology Software Tools Inc., 2016) and Tobii Pro Lab (Tobii Pro AB, 2014) with E-Prime Extensions for Tobii Pro 3.2 (Psychology Software Tools Inc., 2019). Instructions were shown on a Tobii Pro Spectrum 23.8-inch screen with a full-HD 1920 x 1080 resolution.

2.5. Perceived restorativeness

The perceived restorativeness of each picture was assessed by using an adapted version of the perceived restorativeness scale (PRS; Hartig et al., 1997). The PRS has shown to have a good generalizability and sensitivity compared to other self-report scales for the restorativeness of an environment (Han, 2018). Our version consisted of five-items (Table 4), and previous studies have also used shorter versions compared to the original 11-item PRS for their more convenient use in repeated assessments (Berto, 2005; Han, 2018; Nordh et al., 2009; White et al., 2010). First, the participants were instructed to imagine needing restoration and having come to the environment on the picture to relax (Table 4). Then, the first item of the adapted PRS referred to the overall 'perceived likelihood of restoration', similarly as the PRS-1 used in Nordh et al. (2009). This item taps into the possibility for actually experiencing restoration, both emotionally (i.e., relaxing) and cognitively (i.e., regaining mental strength and energy) (Hartig, 2011). The remaining four items drew on attention restoration theory and were derived from earlier studies' short versions of the PRS (Berto, 2005; Han, 2018; Nordh et al., 2009; White et al., 2010). Since there was still some ambiguity in the items reported by the previous literature, we rephrased the items to refer more directly to attention restoration theory's core constructs: being away, fascination, coherence, and compatibility (Table 4). As such, the adapted PRS in this study refers to both the perceived likelihood of restoration in a scenario where the participant would require restoration, as well as to the participants' perceived judgement of environmental characteristics that in theory would foster actual restoration ('perceived restorativeness' or 'environmental quality' or 'restorative potential' (Hartig, 2011). So, both are relying on retrospective and prospective imaginations (Hartig, 2011). Each item was scored on an 11-point Likert scale, which was labelled at 0 with 'totally disagree', at 5 with 'neutral', and at 10 with 'totally agree'. All items were translated to the participants' native language Dutch. The scores from all five items were treated as continuous and averaged to a total score that was used for the analyses (Cronbach's alpha = 0.90, Cronbach's alpha of individual items is available in supplementary materials section 2.1.4). The total score was sufficiently normally distributed for this study's purposes (skewness = -0.20, kurtosis = 2.55, histogram and QQ-plot available in supplementary materials section 2.1.4). We refer to this score of our adapted PRS throughout the study simply as 'PRS'.

Table 4: Description of the instructions and questions of the adapted perceived restoration scale (PRS) that was used in this study as main outcome variable.

Instructions of the PRS (English translation from Dutch presentation)	
"Imagine that you are going through a mentally exhausting period. To relax, you have come to the Belgian coast. During your coastal visit, you are at the place where this picture has been taken. Indicate how strong you agree with the following sentences."	
Item	**Question**
Likelihood of restoration	Here I can relax and regain mental strength and energy.
Being away	Here I am away from obligations.
Fascination	This place seems fascinating.
Coherence	This place seems chaotic.
Compatibility	This place suits with who I am.

2.6. Covariates

The analyses controlled for 33 potential covariates related to the individuals' demography, lifestyle, health, and residential surroundings, which have been shown to be influential in the rating of an environment for its restorativeness. The 33 potential covariates were age, gender, socio-economic status, BMI, physical activity, diet, dog ownership, smoking status, associating the Belgian coast with obligations, number of visits to the Belgian coast in the past three months, number of visits to the Belgian coast in the past year, number of visits to the Belgian coast per year as a kid, residential coastal proximity, satisfaction to residential coastal proximity, near-home urbanization, near-home access to green spaces, near-home access to blue spaces, near-home air quality, near-home noise levels, nature relatedness, coastal relatedness, sleep quality, stress in the past month, burnout score, rumination, sense of coherence, state stress, picture order, period of sampling, momentary outside temperature, momentary outside precipitation, momentary outside wind, and momentary outside humidity. For the reasons for inclusion based on current literature, their measurement, and the Cronbach's alpha scores of the covariates assessed as questionnaires, we refer to supplementary materials section 2.1.1.

2.7. Statistical analyses

Statistical differences and relations between the perceived restorativeness and environments and their components were inferred with general linear mixed models due to their robustness and ability to account for experimentally-induced grouping factors or random effects (Gałecki & Burzykowski, 2013). The inter-environment variation in perceived restorativeness was investigated via a regression-based general linear mixed model (GLMM) with the ten coastal environments as main categorical predictor, PRS as outcome, and with random intercepts for participants and pictures ($N_{participants}$ = 102, $N_{pictures}$ = 52, $N_{observations}$ = 5304). In this model, the pictures of the five intra-beach environments were embedded under 'beach'.

The intra-environment variation in perceived restorativeness within beaches was investigated via a similar GLMM. In this model, the five beach environments were the main categorical predictor, with PRS as outcome, and with random intercepts for participants and pictures ($N_{participants}$ = 102, $N_{pictures}$ = 10, $N_{observations}$ = 1020).

For including the covariates in each model for the inter- or intra-environment variation in PRS, we used an automated forward model selection procedure based on the Akaike Information Criterion (AIC). Lower AIC values indicate better model fit accounted for model complexity (Sakamoto et al., 1986; Zuur et al., 2009), so we searched for the optimal set of covariates with the lowest AIC. To do so, we tested in an iterative way whether and how the AIC changed when adding a covariate in the model. In each iteration, only that covariate that reduced the AIC the most was retained. The end of this iterative process was achieved when the AIC had reached its minimum and none of the remaining potential covariates decreased the AIC. As such, the model only included covariates that were actually relevant.

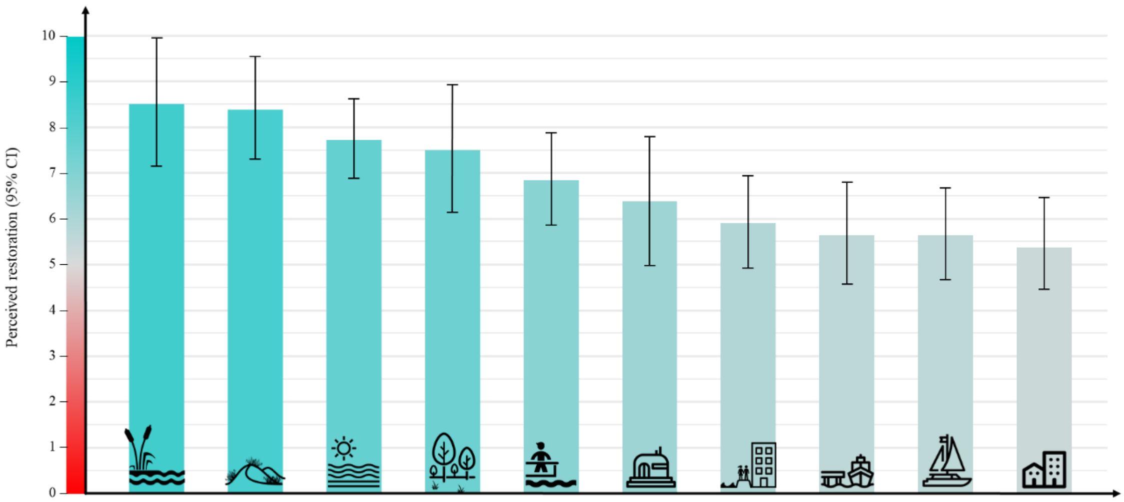
To quantify how each component's dose in our hierarchy influenced the PRS, we constructed separate GLMM's that each had the dose of the component of interest as main continuous predictor, PRS as outcome, and random intercepts for participants and pictures ($N_{participants}$ = 102, $N_{pictures}$ = 52, $N_{observations}$ = 5304). The covariates in each of these models were taken from the model that assessed the inter-environment variation in perceived restorativeness, because this allowed for the interpretations to be comparable between the models.

Significance of the differences in the PRS between the ten coastal environments and five beach environments was assessed by Tukey-corrected p-values of the estimated marginal means at $\alpha = 0.05$. Significance of the effects of the components' doses on the PRS was assessed at $\alpha = 0.05$ with Benjamini-Hochberg correction to control for false discovery rate (Benjamini & Hochberg, 1995). Model assumptions were a normal distribution of the residuals and independency of observations relative to the random effects. These assumptions were checked by visually inspecting the modelled residuals over the fitted values, and by assessing whether the random variance was lower than the residual variance. All analyses were performed in R (R Core Team, 2018), and GLMMs were developed with the *lme4* package (Bates et al., 2015).

3. Results

3.1. Inter-environment variation in the perceived restoration

The first analysis compared the PRS-scores of ten coastal environments representative for the Belgian coast via a general linear mixed model. Most importantly, Figure 13 shows that the estimated marginal means of PRS-scores for the ten coastal environments differ gradually, with more natural environments scoring higher. More specifically, the PRS rating of the environments was in decreasing order: salt marshes, dunes, beaches, green parks, piers, historical sites, dikes, docks, recreational harbors, and towns (Figure 13). Salt marshes had the highest PRS (i.e., 8.54/10), and towns the lowest (i.e., 5.46/10). So, the perceived restoration of the 10 coastal environments differed up to 30%, was neutral to positive, and seemed to associate with the environments' 'naturalness'. The model that compared these ten coastal environments explained 33.4% (marginal R^2) of the variation in the PRS scores of the 52 included pictures, of which 6.1% was attributed to the inclusion of covariates. The model controlled for the residential perception of air quality ($p < 0.001$), stress in the past month ($p = 0.003$), smoking status ($p = 0.020$), having a work-relationship with the coast ($p = 0.026$), and gender ($p = 0.066$). Detailed reports on the final model formulation, tested assumptions, variances, ANOVA estimates, and pairwise differences, for models with and without covariates, can be found in supplementary materials section 2.2.1.

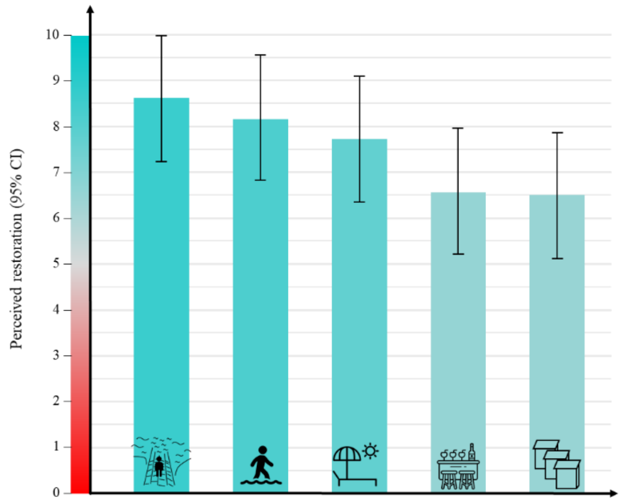


Coastal environments	Salt marshes	Dunes	Beaches	Green parks	Piers	Historical sites	Dikes	Docks	Recreational harbors	Towns
Upper 95% CI	9.94	9.53	8.61	8.92	7.86	7.79	6.93	6.81	6.67	6.47
EM Mean	**8.54**	**8.41**	**7.75**	**7.53**	**6.86**	**6.39**	**5.92**	**5.69**	**5.66**	**5.46**
Lower 95% CI	7.14	7.29	6.88	6.13	5.85	4.99	4.91	4.57	4.66	4.45
Different environments ($p < 0.05$)										

Figure 13: Inter-environment variation in perceived restorativeness: estimated marginal means of PRS-scores of ten coastal environments identified at Belgian coast. Differences between environments were deduced from pairwise comparisons with Tukey-corrected p-values at α = 0.05, which are visualized here as shared lines between environments for which no significant differences were found. So, two environments differ significantly if they do not share a line (e.g., the PRS-scores of piers differ significantly from those of salt marshes, dunes, recreational harbors, and towns). Illustrations are purely aesthetic, we refer to the actual pictures for accurate representations of the environments (https://doi.org/10.14284/560; Hooyberg et al., 2022). Abbreviations: CI = Confidence Interval; EM Mean = Estimated Marginal Mean.

3.2. Intra-environment variation in the perceived restoration

The second analysis looked at whether different types of environments within the beach were associated with different PRS-scores via a second general linear mixed model. Figure 14 shows that the PRS-scores of five different beach environments differed up to approximately 20%. More specifically, pictures taken on breakwaters scored better than those taken between beach cabins and those taken in beach bars. No differences were found between the PRS-scores of pictures taken from in the seawater and those taken at open beaches. The model that compared these five beach environments explained 34.1% (marginal R^2) of the variation in the PRS scores of the 10 included pictures, of which 14.9% was attributed to the inclusion of covariates. These results are controlled for the participants' gender ($p < 0.001$), coastal relatedness ($p = 0.002$), burnout score ($p = 0.008$), diet ($p = 0.012$), smoking status ($p = 0.006$), residential green access ($p = 0.033$), and residential air quality perception ($p = 0.006$). Detailed reports on the final model formulation, tested assumptions, variances, ANOVA estimates, and pairwise differences for models with and without covariates can be found in supplementary materials section 2.2.2.



Beach environments	On a breakwater	In the seawater	Open beach	In a beach bar	Between beach cabins
Upper 95% CI	9.99	9.57	9.12	7.97	7.88
EM Mean	**8.62**	**8.20**	**7.74**	**6.59**	**6.50**
Lower 95% CI	7.24	6.82	6.37	5.22	5.13
Different environments ($p < 0.05$)					

Figure 14: Intra-environment variation in perceived restorativeness: estimated marginal means of PRS-scores of five beach environments identified at Belgian coast. Differences between environments were deduced from pairwise comparisons with Tukey-corrected p-values at α = 0.05, which are visualized here as shared lines between environments for which no significant differences were found. So, two environments differ significantly if they do not share a line (e.g., the PRS-scores of on a breakwater differ significantly from those of in a beach bar, and between beach cabins). Illustrations are purely aesthetic, we refer to the actual pictures for accurate representations of the environments (https://doi.org/10.14284/560; Hooyberg et al., 2022a). Abbreviations: CI = Confidence Interval; EM Mean = Estimated Marginal Mean.

3.3. Influence of natural and urban components and people on PRS

The third set of analyses explored which natural, urban, and/or social components on the pictures were positively and negatively associated with the PRS-scores. Table 5 shows that, at the highest level, the PRS-scores were highly associated with the dose of natural components (positive effect, $\beta = 3.175 \pm 0.304$, $p < 0.001$, $R^2 = 0.300$) and urban components (negative effect, $\beta = -3.263 \pm 0.308$, $p < 0.001$, $R^2 = 0.302$). This 'naturalness'-effect also held for the lower-level constituents, although with smaller magnitudes of effect sizes and explained variation (Table 5). Specifically, significant associations were positive for mostly natural lower-level constituents, namely for vegetation (in general and for dune vegetation), seawater on the beach (not water in general), sky, natural underground (in general and for sandy underground), and breakwaters. Negative associations were always with urban lower level components, namely buildings (in general and for shops and unspecified buildings), anthropogenic disturbances (in general and for vehicles), urban undergrounds (in general and hard undergrounds other than streets), distant landscapes (in general and for recreational harbors), and unclassified urban components. There was a negative trend that showed that an increasing dose of people tended to be associated with strong adverse effects on the PRS ($\beta = -19.684 \pm 9.593$, $p = 0.105$, $R^2 = 0.088$). However, it seemed that people and some low-level components resulted in unrealistic model estimates, most likely because they were low in prevalence and had low ranges in their doses (i.e., β-estimates above 10 for people, flower box, brackish water, seawater on beach, marine debris, wildlife, litter, vehicle, bench, shops, buoy, play and sports, professional equipment, coastal defense, pier, big harbor, construction, bin, unclassified urban). All the associations were controlled for the same covariates as the model for the inter-environment comparison. For each modelled association, the corresponding linear regression graphs and more details of the model output estimates are available in supplementary materials section 2.2.3.

Table 5: General linear mixed model output and correlations of the relationships between the picture components and the Perceived Restorativeness Scale (PRS). Each line indicates the output from a separate model.
Abbreviations: β = model estimate, SE = Standard Error, df = degrees of freedom, BH = Benjamini-Hochberg, R^2 = explained variation, r = Pearson correlation.
* Covariates accounted for approximately 6.1% of the explained variation, this variation is still included in the $R^2_{marginal}$ values.

	Model estimates						
Component	**β**	**SE**	**df**	**t-value**	**p-value (adjusted BH)**	**R^2 (marginal)**	**r**
Natural	3.175	0.304	50	10.439	< 0.001	0.300	0.493
Vegetation	2.001	0.693	50	2.885	0.020	0.110	0.225
Landplant	0.101	0.971	50	0.104	0.935	0.061	0.009
Dune vegetation	3.882	1.080	50	3.595	0.004	0.132	0.270
Salt marsh vegetation	5.467	2.462	50	2.221	0.078	0.092	0.178
Flower box	-377.407	226.985	50	-1.663	0.207	0.079	-0.136
Water	2.302	1.549	50	1.486	0.255	0.076	0.122
Brackish water	33.271	15.372	50	2.164	0.085	0.091	0.174
Seawater	1.953	1.548	50	1.262	0.338	0.072	0.105
Still water	-0.377	2.154	50	-0.175	0.896	0.061	-0.015
Waves	4.146	2.360	50	1.757	0.188	0.081	0.143
Seawater on the beach	50.084	15.629	50	3.204	0.010	0.120	0.246
Sky	3.344	1.020	50	3.277	0.008	0.122	0.250
Blue sky	0.470	1.533	50	0.307	0.840	0.062	0.026
Delineated cumulus	3.392	1.477	50	2.296	0.069	0.094	0.184
Non-delineated cumulus	3.350	1.956	50	1.713	0.197	0.080	0.140
Stratus and cirrus	0.362	1.309	50	0.277	0.847	0.062	0.023
Natural underground	3.108	0.809	50	3.840	0.002	0.140	0.284
Sand underground	3.492	0.831	50	4.203	< 0.001	0.152	0.304
Grass underground	-9.280	7.168	50	-1.295	0.334	0.072	-0.107
Marine debris	15.099	12.079	50	1.250	0.338	0.071	0.104
Wildlife	929.756	1050.400	50	0.885	0.530	0.066	0.074
Urban	-3.263	0.308	50	-10.587	< 0.001	0.302	-0.495
Building	-4.670	1.019	50	-4.584	< 0.001	0.164	-0.324
Shops	-13.929	5.014	50	-2.778	0.025	0.107	-0.218
Unspecified building	-5.615	1.192	50	-4.709	< 0.001	0.168	-0.330
Tower	7.557	12.492	50	0.605	0.691	0.063	0.051
Anthropogenic disturbance	-185.315	55.713	50	-3.326	0.008	0.124	-0.253
Vehicle	-344.178	83.039	50	-4.145	< 0.001	0.150	-0.301
Litter	-212.280	200.540	50	-1.059	0.427	0.069	-0.088

Bench	-40.805	78.583	50	-0.519	0.747	0.063	-0.044
Coastal object	0.760	1.617	50	0.470	0.754	0.063	0.039
Beach bar infrastructure	-0.182	2.655	50	-0.069	0.946	0.061	-0.006
Beach cabin	-0.637	2.999	50	-0.212	0.883	0.061	-0.018
Buoy	2519.649	1599.077	50	1.576	0.230	0.077	0.129
Historical object	-1.463	3.374	50	-0.434	0.768	0.062	-0.036
Play and sports objects	46.881	139.678	50	0.336	0.833	0.062	0.028
Single boat	-5.832	5.406	50	-1.079	0.427	0.069	-0.090
Breakwater	8.585	3.413	50	2.515	0.042	0.100	0.199
Coastal defense	12.467	16.544	50	0.754	0.618	0.065	0.063
Professional equipment	64.272	97.250	50	0.661	0.678	0.064	0.055
Urban underground	-4.729	0.711	50	-6.651	< 0.001	0.224	-0.408
Street	-4.681	2.837	50	-1.650	0.207	0.079	-0.135
Hard underground	-4.313	0.778	50	-5.542	< 0.001	0.193	-0.367
Distant landscape	-4.431	1.623	50	-2.730	0.027	0.106	-0.214
Pier	-31.888	52.674	50	-0.605	0.691	0.063	-0.051
Recreational harbor	-4.367	1.620	50	-2.696	0.028	0.105	-0.212
Big harbor	194.221	393.615	50	0.493	0.751	0.063	0.041
Bin	-20.065	19.087	50	-1.051	0.427	0.068	-0.087
Balustrade	-4.747	3.288	50	-1.444	0.265	0.075	-0.119
Constructions	-128.835	86.897	50	-1.483	0.255	0.076	-0.122
Unclassified urban	-10.991	3.492	50	-3.147	0.011	0.118	-0.242
People	-19.684	9.593	50	-2.052	0.105	0.088	-0.166

4. Discussion

4.1. Main results

This study investigated the inter- and intra-environment variation in the perceived restorativeness along the Belgian coast, and the influence of the environment's natural and urban components and people.

In the first part of this study, we compared the perceived restorativeness of ten coastal environments and five beach environments representative for the Belgian coast. Previous research either regarded coastal areas as a whole or focused on only some coastal environments (e.g., White et al., 2021), such as urbanized beaches or coastal towns (e.g., (Vert et al., 2020), and it was yet unclear how various types of coastal environments benefit health differently (Hooyberg et al., 2020). This study provides evidence that more natural coastal environments, including beaches, salt marshes, and dunes, scored consistently and up to 30% higher on the perceived restorativeness than the neutrally scoring urban environments, including towns, harbors, dikes (Figure 13; Figure 14). We found similar results on a “micro-level” at the beach, where being on a breakwater was associated with higher perceived restorativeness compared to being in a beach bar or between beach cabins (being at the open beach or in the seawater scored moderately good). Thus, this study reveals that the magnitude of perceived restorativeness in coastal areas is positive to neutral, highly location-specific, and related to the environments’ ‘naturalness’.

The adapted perceived restorativeness scale (PRS) used in this study referred to both the perceived restorativeness (or restorative quality/potential) of the environment based on attention restoration theory as to the perceived likelihood of emotional restoration (Han, 2018; Hartig et al., 1997; see also Methods section 2.4). More specifically, four of the five constructs in our adapted perceived restorativeness scale referred to feelings of fascination, being away, coherence, and compatibility. According to the attention restoration theory, environments that score higher on these constructs can more easily restore directed attention resources, which are needed to cope with everyday challenges and demands (Hartig et al., 1997; R. Kaplan & Kaplan, 1989; S. Kaplan, 1995). The fifth construct in our scale asked for the likelihood of relaxation and mental restoration in the specific environment. Hypothesized is that such emotional restoration (e.g., stress-reduction) originates from early humans’ adaptive responses to natural environments (Ulrich, 1981, 1983; Ulrich et al., 1991). In that respect, the natural coastal environments in this study would have been rated better because these environments would be higher in prospect and lower in refuge (Appleton, 1977), remind more of early human’s savannah habitats (Orians, 1980; Orians & Heerwagen, 1992), and act more on biophilia (Wilson, 1984) than urban environments would. All scores were highly consistent with the scores of the other four constructs, and it is hypothesized that all rely on retrospective perceptions about the past experiences with the coastal environments that are prospected to a future hypothetical scenario where one would be in the environment and in need of restoration (Hartig, 2011).

The results of this study stem from a female-dominated student population (83% female, 18-24-year-old) that was largely residing in inland regions. Previous studies have shown that people with a different age, gender, and residential proximity, among other personal characteristics, may perceive the restorativeness of various environments in different ways (Neilson et al., 2016, 2017; T. Nguyen et al., 2018; White et al., 2010), potentially due to the differences in perceived levels of safety (Jiang et al., 2017), prerequisites for restoration such as being away (Hartig et al., 1997), and previous experiences and desired activities, including mobility (Elliott et al., 2018). Such sociological drivers may explain why this study finds that students rate urban coastal environments as neutral and not as positive, while these urban coastal environments still seem to be very popular and highly valued by elderly coastal residents and tourists. In any case, from the literature it seems that the perceived restorativeness being higher for more natural (coastal) environments is a population-wide phenomenon (see introduction).

In the second part of this study, we confirmed and refined the influence of the environments’ ‘naturalness’ by revealing that the perceived restorativeness was positively associated with the doses of natural components on the pictures, and negatively with the doses of urban components. Remarkably, the dose of natural and urban components and their embedded lower-level constituents accounted for 30% of the total variation in the perceived restorativeness. This was almost equal to the 33.4% of the variation that was explained by the inter-environment differences in the first part of this study (both percentages include the 6.1% variation explained by the covariates). As such, our findings not only confirm the effect of naturalness on restoration such as found in previous literature (e.g., (Gascon et al., 2015; Jiang et al., 2016; Karmanov & Hamel, 2008; Labib et al., 2020b; Lindal & Hartig, 2015; Liu et al., 2022; Neilson et al., 2017; T. Nguyen et al., 2018; Nordh et al., 2009; White et al., 2010), but also highlight the relative importance of this naturalness-effect respective to other aspects of the (coastal) environment (e.g., social).

Despite that the people on the pictures in our study only explained a limited amount of variation (i.e., about 9% including the variation explained by the covariates), and their doses were generally too low (i.e., 0-7%) for conclusions to be made, they have potentially contributed to substantially lower scores for restorativeness. In general, depending on the amount and type of people, the restorativeness of an environment may range from highly positive when the presence of people from similar social classes increase opportunities for strengthening social cohesion and social aspects of well-being (Ashbullby et al., 2013; Maguire et al., 2011; Oh et al., 2010), to highly negative when there is overcrowding and decreased feelings of safety (Ashbullby et al., 2013; Herzog & Rector, 2009; Nordh et al., 2011; Staats & Hartig, 2004). Since these patterns may be especially relevant in coastal areas (e.g., mass summer tourism vs. desertedness in winter), we should note that the dose-effect of people in coastal areas is probably context and time dependent, and the underlying sociological pathways are worthy for further investigation.

Our statistical analyses on the doses of the hierarchically classified lower-level natural and urban constituents revealed how much the restorativeness varied with every type of component found on our pictures, including some well-discussed (e.g., vegetation, water) and lesser-discussed components (e.g., skies). Since this study used realistic pictures and not ones with manipulated components, it is important to consider three naturally-occurring dependency-effects before interpreting the reported dose-response effects. Firstly, since the space in an environment or on a picture is limited, an increase in the dose of one component automatically results in a smaller dose of the other components. Consequently, the effects associated with an increased dose of a specific component may actually reflect the effects from the decreased doses of other components. Secondly, the measured response to a particular component may not reflect the effect of the actual component per se, but rather the response to the component's characteristics, such as its color, fractal pattern, or complexity (Franěk et al., 2019; Joye et al., 2016; Kaplan et al., 1972; Michels et al., 2021). Thirdly, on our non-manipulated pictures the component of interest may frequently co-occur with other components, whose effects may obscure the effect of the component of interest. Considering these dependency effects, in the next paragraph we provide an overview of the natural and urban components of which their increasing doses significantly impacted the perceived restorativeness, and what we can draw from our results with respect for the findings from the literature.

The dose-response effects of our lower-level natural components generally agree with what was found in the literature. Firstly, our results confirm a positive dose-effect of vegetation, which has also been extensively described previously (Jiang et al., 2014, 2015, 2016; T. Nguyen et al., 2018; Nordh et al., 2009; Ulrich et al., 1991; White et al., 2010). In our study, dependency-effects with other components are deemed to be negligible, because the vegetation cover took more than 10% of the picture on 14 pictures from diverse environments and ranged from 0% to over 80% on these pictures. In contrast, we did not find a dose-effect of water. White et al. (2010) proposed the existence of such a dose-effect of water, and a large amount of observational studies showed that the (amount of) visible (sea-)water in blue spaces improves health outcomes (Charlier & Chaineux, 2009; Cracknell, 2019; Dempsey et al., 2018; Garrett, White, et al., 2019; Nutsford et al., 2016; Peng et al., 2016b). However, this study and previous follow-up experiments of White and colleagues' study (2010) with manipulated picture components could not replicate the dose-effect of water (Neilson et al., 2016, 2017; T. Nguyen et al., 2018). Therefore, it has been argued that either there is spatial variation in the dose-effect of water (e.g., cross-country, inland vs. coastal, among types of environments, drinkable vs. non-drinkable), or that the effects are dependent on the population and/or context (e.g., cultural or demographic differences, during visits vs. from the residence; (T. Nguyen et al., 2018; Ulrich et al., 1991; White et al., 2020). Since we did not observe a higher perceived restorativeness of docks and recreational harbors compared to towns and dikes without water, the dose-effect of water seems to be practically absent along the Belgian coast. A lesser-known, but interesting, dose-effect found in this study is that of the sky (in its totality, not of blue skies or clouds separately). Sky visibility was positively associated with restorativeness and explained up to 6% of the variation. The literature about the psychological experiences in response to skies is scarce, but Masoudinejad and Hartig (2020) also found that skies in experimentally controlled cityscapes increased restoration likelihood judgments, similarly as environments with higher levels of prospect and refuge, sense of spaciousness, and safety (Lindal & Hartig, 2013; Stamps, 2005). In both the study of Masoudinejad and Hartig (2020) and our study, dependency-effects between sky visibility and building height seem especially prominent, which limits our ability to deduce whether the effect comes from decreased building height or increased sky visibility. A last dose-effect of natural components found in this study was a positive association between sandy undergrounds and the restorativeness. To our knowledge, no direct investigations for the effects of sandy undergrounds have been performed. However, seeing more sand in realistic environments would automatically result in a larger extent and spaciousness, which benefits restoration (R. Kaplan & Kaplan, 1989). Interestingly, sand as a particular type of underground can also make the coastal experience more unique by being integral to many coastal activities (e.g., walking, play and sports; Ashbullby et al., 2013; Elliott et al., 2018).

In contrast to the dose-effects of natural components, urban components' dose-response effects were usually negative. Significant decreases in the perceived restorativeness were associated with an increased dose of buildings, vehicles, hardened undergrounds, and distant urban landscapes. To our knowledge, no previous study has directly investigated the dose-effects of such components on the perceived restorativeness, except for the study of Masoudinejad and Hartig (2020) that tested for the ratio building/sky visibility from a window, of which the interpretation is troubled by the before-mentioned dependency-effects. Noteworthy is that the magnitude of restoration may also change with building architecture (Lindal & Hartig, 2013), levels of upkeep (including the presence of litter; Van Hecke et al., 2018; Wyles et al., 2016), and traffic-related disturbances (von Lindern et al., 2016). The urban environments in our study were usually well-maintained, so this may have caused the overall scores for these urban environments to be only neutral and not detrimental. In any case, most coastal urban environments also seem to associate with a more holiday-like appearance and more opportunities for leisure compared to the average inland urban environments, and this may have further protected them against being rated worse by the participants.

4.2. Limitations and strengths

This study's holistic approach and innovative methods coincide with some noteworthy limitations. Firstly, focusing on Belgian coastal environments has made the results of this study difficult to compare with most of the previous studies' comparisons of green, blue, and urban spaces and with types of coastal environments that are not found in Belgium, such as rocky shores (White et al., 2010; Wyles et al., 2014). Nevertheless, many of the Belgian coastal environments are similar to those in many other urbanized and touristic coastal areas (e.g., beaches, towns, dikes). Secondly, the female-dominated students recruited in this study differed in traits, motivations, and behaviors from the typical Belgian population and Belgian coastal visitors, which may have resulted in student-specific and largely female-specific scores for the perceived restoration (Browning et al., 2021). Thirdly, the use of a picture-rating study inherently associates with some methodological challenges with regard to the representativeness of the pictures for the real environments, the validity of the perceived restorativeness ratings for the actually occurred restoration, and the influences of attentional processes driven by experimental, individual, and contextual factors while observing those pictures (Browning et al., 2021; Hartig et al., 2014, 1997; White et al., 2020). However, a particular strength of this study is that these challenges were highlighted in a newly developed diagram (Figure 9), and were tackled by assembling a well-standardized picture-set, adopting a valid experimental procedure with a well-performing adapted perceived restorativeness scale, and controlling for many participant-related covariates. In any case, pictures would not be less likely to result in altered effects than more immersive simulations (Browning et al., 2021; Velarde et al., 2007), and subjective measures are often a good reflection of objectively experienced restoration (Subiza-Pérez et al., 2020). Lastly, the components were only investigated linearly, and not by other curvatures (e.g., power-line as in Jiang et al., 2015), which may have simplified the results unjustly. This study's aims were to be exhaustive rather than focused, which resulted in new insights about important dependency-effects, and in the unveiling of many impactful and non-impactful natural, urban, and social components.

4.3. Avenues for future research

Understanding how outdoor environments impact psychological restoration is a prerequisite for sustainable spatial design and the development of novel therapeutic practices in the cost-effective treatment and prevention of poor mental health (UNEP, 2019). This study has captured the inter- and intra-environment variation in perceived restorativeness and the influence of natural and urban components and people, but while doing so focused purely on visual exposures and the perceived restoration thereof. Therefore, future research is necessary if restorative (coastal) outdoor environments are to become clinically applicable. More specifically, additional insights should be gathered about how multi-sensorial and immersive experiences (e.g., virtual or real) impact on psycho-physiological measures of restoration (e.g., cognitive task performance or psycho-physiological measurements), and how the effects may differ among populations with a different demographic and socio-economic background and state mental health (Browning et al., 2021; Wooller et al., 2016). Additionally, spatiotemporal risk factors should be identified, including those related to climate and weather (e.g., time of the year), crowding, and litter (Hipp & Ogunseitan, 2011; White, Cracknell, et al., 2014; Wyles et al., 2016). Architectural designs already incorporate many preferred natural and urban components (e.g., street greenery), but it seems that more research is necessary to reveal their actual psychological benefits (e.g., Bell et al., 2020; van den Bogerd et al., 2021). While addressing these knowledge gaps, current theoretical frameworks should remain to be updated and tested in ecologically valid scenarios (Collado et al., 2017; Hartig et al., 2014; Stevenson et al., 2018). Lastly, the short-term and long-term clinical and societal benefits of exposure to different coastal environments should be quantified in economic value and their cost effectiveness should be outweighed with respect to other treatments for mental health (Papathanasopoulou et al., 2016). If exposure to restorative coastal environments would prove to be cost-effective, then sharing literacy about the coast’s therapeutic value with the health sector, public, and tourism sector may provide beneficial ripple-effects through society (Roberts et al., 2021; Sandifer et al., 2021).

5. Conclusion

This study aimed to quantify the inter-environment and intra-environment variation in the perceived restorativeness along the Belgian coast and to quantify the influence of natural and urban components and people on the restorativeness. To do so, 52 pictures of ten coastal environments and five beach environments representative for the Belgian coast were rated on an adapted perceived restorativeness scale by 102 students, and methodological challenges for the validity of this picture-rating study were identified and tackled. The data was analyzed by a series of general linear mixed models that controlled for individual and study-design related factors. The results demonstrated that more natural coastal environments were rated up to 30% more positive than the neutrally scoring urban coastal environments. This naturalness-effect largely coincided with positive dose-response effects of vegetation, sky visibility, and sandy undergrounds (not water), and negative dose-response effects of buildings, vehicles, hardened undergrounds, and distant urban landscapes. The effect of people remains uncertain, but interesting for future research since this study saw a potentially large impact of people on the restorativeness. Taken together, the results of this study confirm and greatly refine previous perspectives about coasts’ high restorative potential (Hooyberg et al., 2020), and avenues for future research are proposed for cost-effectively preventing and treating poor mental health.

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The psychophysiological reactivity to beaches vs. to green and urban environments: insights from a virtual reality experiment

Adapted from Hooyberg, Michels, et al. (2023)

Abstract

Coastal environments effectively reduce perceived levels of stress. However, little is known about whether coastal environments influence physiological parameters of stress, whether these influences differ from those of urban and green environments, and whether these effects depend on the level of precedent stress. The current study exposed 164 participants (18-65y, 68% female) from the Flemish population to two 16-minute virtual reality exposures (i.e., beach vs. green or urban) via a randomized cross-over design, during which the heart rate, high-frequency heart rate variability (HF-HRV), skin conductance responses (SCR), mean arterial pressure (MAP), breathing rate, and upper trapezius muscle tone were monitored. Self-reported measures of stress were also taken. General linear mixed models analyzed for each parameter whether the change over time differed per exposed environment and by the level of stress in the past week (from 'low' to 'moderate' levels), while controlling for study design and participant related covariates. Results show that beaches caused lower breathing rates than urban environments and lower SCR than green environments. The upper trapezius muscle tone showed complex patterns, and the heart rate, HF-HRV, and MAP did not react differently to the beach than to the urban and green environments. The individuals' level of stress in the past week did not affect these differences much. Self-reported measures showed that, under moderate stress, beaches decreased the negative mood and perceived stress, whereas green environments did not and urban environments generally had more adverse effects on the negative mood, perceived stress, positive mood, and perceived quality for relaxation. This study demonstrates that beaches slow down breathing and reduce the sympathetic nervous system activity, and highlights the benefits of beaches for health and well-being. The results mark the importance of considering diverse physiological pathways of stress and the individuals' precedent stress.

Keywords

Coastal landscape, Health benefits, Psychophysiological responses, Stress reactivity, Virtual reality

1. Introduction

Coastal destinations are popular resources for recreation and health (Gammon & Jarratt, 2019). More than 47% of the total recreational overnight stays in the European Union are spent in coastal municipalities (2012-2022; Eurostat, 2022),[3] and stress-relief is one of the main experiences that people report when visiting the coast (Ashbullby et al., 2013; S. L. Bell et al., 2015). It is reasonable to assume that internal physiological mechanisms are causing these perceived benefits. However, to strengthen the evidence of these effects, it is vitally important to acquire more knowledge of the physiological mechanisms (Frumkin et al., 2017; H2020 SOPHIE Consortium, 2020).

The physiology of stress is regulated by the central nervous system, which perceives the environment as calming or arousing based on the information that it receives from the different sensory organs (Cardinali, 2018; Godoy et al., 2018). Depending on the perceived context, the central nervous system increases or decreases the level of arousal by up- or downregulating pathways of the somatic nervous system and the sympathetic and parasympathetic branches of the autonomic nervous system (Chrousos, 2009; Godoy et al., 2018). The arousal may have a valence that is negative (e.g., during stress) or positive (e.g., during excitement). The pathways that have proven to be highly sensitive to changes in arousal and that can be relatively easily measured by non-invasive procedures include those that regulate the heart rate, heart rate variability, sweat production, blood pressure, breathing rate, and muscle tone, among others (Berto, 2014; Corazon et al., 2019; Haluza et al., 2014; Jo et al., 2019; Shuda et al., 2020). Importantly, measuring multiple of these endpoints simultaneously can provide complementary insights about the underlying functional regulatory mechanisms in response to the environment (Cacioppo et al., 2007; Ulrich et al., 1991).

Beaches are among the most effective coastal environments for reducing stress and improving mood (Ashbullby et al., 2013; S. L. Bell et al., 2015; Hipp & Ogunseitan, 2011; Hooyberg, Michels, et al., 2022; Peng et al., 2016b, 2016a; Severin et al., 2022; White et al., 2010; Wyles et al., 2016), but only four studies have investigated how beaches influence the physiology of stress (Anderson et al., 2017; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015). Furthermore, the participants in three of these four studies were physically active (e.g., roaming free; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015), while physical activity may activate the same physiological pathways as those involved in the stress-response (Dahn & And, 2005; Katayama & Saito, 2019; Miyamoto et al., 2022; Triguero-Mas et al., 2017). Virtual reality provides a valid alternative for environmental exposure in the lab in an almost equally immersive way, and this while the participant can remain stationary (Annerstedt et al., 2013; Browning et al., 2021; Browning, Mimnaugh, et al., 2020; Browning, Shipley, et al., 2020; Gao et al., 2019; Litleskare et al., 2020; Tanja-Dijkstra et al., 2018; White et al., 2018; Yeo et al., 2020). Three of the four studies that tested the physiological responses to beaches also tested the responses to

[3] Municipalities that border the sea or have half of their territory within 10 kilometers of the sea.

green environments, but none of these studies seem to have assessed analytically whether the effects of the beaches differed from those of the green environments (Anderson et al., 2017; Triguero-Mas et al., 2017; White et al., 2015). Additionally, only cardiovascular and electrodermal physiological responses have been measured (Anderson et al., 2017; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015), and knowledge of muscular and respiratory responses would provide more comprehensive insights (Cacioppo et al., 2007). On top of these issues, the law of initial values states that the magnitude of any physiological response depends on the pre-stimulus level of that parameter (Block & Bridger, 1962; Wilder, 1958). This emphasizes the importance of carefully considering each participant's initial level of stress when measuring the physiological pathways of stress. Altogether, no study has yet compared how the beach impacts cardiovascular, respiratory, and muscular pathways differently than outdoor urban and green environments, while excluding physical activity from the exposure and considering that the effect sizes depend on the initial levels of stress of the participants.

The current study aimed to investigate how diverse physiological parameters of stress respond differently to beaches, green, and outdoor urban environments for people with different and naturally varying levels of initial stress. The physiological parameters of interest were chosen to be indicative of diverse autonomic and somatic innervations and included the heart rate, high-frequency heart rate variability (HF-HRV), skin conductance responses (SCR), mean arterial pressure (MAP), breathing rate, and upper trapezius muscle tone. Since physiological parameters display solely arousal and not valence, also self-reported parameters of the positivity and negativity of the situation were measured: i.e., positive and negative mood, perceived stress, and the perceived quality of the environment for stress-recovery. To assess the effects of the initial level of stress, the stress level of the past week was included as an essential moderating factor in the analyses.

It was hypothesized that the virtual exposure to the beach would result in a lower physiological arousal and improved self-reported parameters compared to the urban and green environments. Any change from pre- to post-stimulus would be prone to floor and ceiling effects depending on the stress level in the past week.

2. Materials and methods

2.1. Study design and protocol

This study adopted a randomized cross-over design with two periods (VR1 and VR2), three treatments (beach, green, or urban exposure), and four randomized sequences (beach-green, beach-urban, green-beach, and urban-beach; Figure 15). The procedure consisted of a habituation period, the two exposures with two rest periods before each exposure for physiological baseline measurements, and measurement periods before (T0), in-between (T1), and after (T2) each exposure to measure the self-reported parameters (Figure 15). To minimize possible carryover effects between the two periods, T1 also served as a washout period.

Changes in the physiological parameters of stress were measured continuously throughout the experiment via the electrocardiogram (for heart rate and HF-HRV), skin conductance (for SCR), pulse plethysmography (for MAP), respiration signal (for breathing rate), and electromyogram (for upper trapezius muscle tone). Calculations on these signals were done for two 2-minute sections in the 5-minute baseline and eight 2-minute sections during the 16-minute exposures (Figure 15). These sections and their duration were chosen based on standard guidelines for measuring psychophysiological parameters and to be able to detect both slow and rapid changes during the baselines and exposures (Benedek & Kaernbach, 2010; Berntson et al., 1997; Laborde et al., 2017; Malik et al., 1996).

The self-reported positive and negative mood and perceived stress were measured via questionnaires at T0, T1, and T2 to compare the changes from pre-exposure to post-exposure (Figure 15). For these parameters, T1 served as both a post-measurement for the first exposure and a pre-measurement for the second exposure. The perceived quality of the environment for relaxation was assessed via a questionnaire at T1 and T2 about the preceding exposures (Figure 15).

A week before the experiment, an online questionnaire assessed the participants' demographics, previous environmental exposures, state mental health, and personality. To be noted is that the experiment included additional continuous physiological measurements and cognitive assessments at the ends of T0, T1, and T2. The authors consider that these alterations could not have had an impact on the results. The study was conducted by The Code of Ethics of the World Medical Association for experiments involving humans (the Declaration of Helsinki) and was approved by Ghent University's Medical Ethical Committee. The experiment took place on workdays starting at 9 a.m., 12 p.m., or 3 p.m. between July 7th and September 24th, 2021, at the Flanders Marine Institute in Ostend or at the Ghent University Hospital in Ghent.

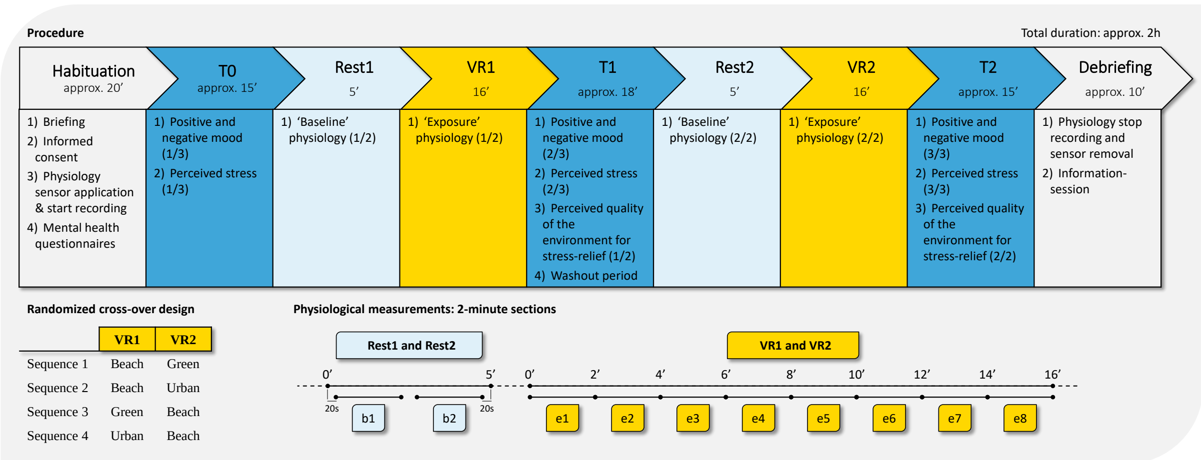

Figure 15: The procedure of the virtual reality (VR) experiment, the sequences of the randomized cross-over design, and the two-minute sections on which the analysis of the physiological measurements were based. The enumerations of the actions listed beneath the steps in the procedure reflect the actual order of these actions. T1 served as washout period to minimize possible carry-over effects between the first (VR1) and second (VR2) VR exposure.

2.2. Participants and recruitment

The virtual reality experiment was carried out on 164 healthy adults (18-65 years old, 68% female, Table 6) from the Dutch-speaking Flemish population. The sample size was assured to be higher than that in most previous studies that assessed the effects of (virtual) nature simulations on psychophysiological parameters (Browning et al., 2021; Browning, Mimnaugh, et al., 2020). No a priori power calculation was performed due to the complex interaction- and random effects and an initially unknown number of covariates (see section 2.8 Statistical analyses).

Participants were recruited through a media campaign that informed and attracted potential participants via a press release, website (‘*www.uitzicht.org*’), and Facebook page (‘*Uitzicht.onderzoek*’). Potential participants were informed about the goal and practicalities of the study but were blinded to the types of environments they could be exposed to during the experiment. They were also informed that there would be no financial compensation, but that in exchange for their participation, their personalized results would be shared with them privately after the experiment during an information session. The recruitment happened in three waves, each involving pre-selection and invitation (a flow chart of the participant recruitment is available in the supplementary materials section 3.1.1). The exclusion criteria were being pregnant, having a (chronic) disease of the heart (e.g., pacemaker), having a psychological/neurological/motor disorder or any other condition that prevents from functioning normally, taking medication for mental health (e.g., for stress), being sensitive to severe motion sickness, being visually or hearing impaired (including color blindness) even with corrective measures (e.g., through glasses, lenses or hearing aids), and having fears related to the environment (e.g., fear of water). All communication with the participants, including the questionnaires, was conducted in Dutch, the participants' native language.

Table 6: Demographics table. The table depicts for each categorical parameter the factor levels and the number of participants per factor level and for each continuous parameter the range and mean and standard deviation per group (beach, green, or urban exposure). Abbreviations: SES = socio-economic status; BMI = body-mass index; IPAQ = international physical activity questionnaire; DASS = depression, anxiety, and stress scale
[a] Ranges correspond to the theoretically possible minimum and maximum values.
[b] X statistic from a Chi-Square test for categorical variables. F statistic from an ANOVA for continuous predictors.

		N per level or Mean (SD)			X or F statistic[b]	p
		Beach = Total	Green	Urban		
Parameter	**Levels or [Range][a]**	**N = 164**	**N = 55**	**N = 55**		
Design						
Period	First VR, Second VR	81, 83	28, 27	27, 28	1.35	0.51
Experiment location	Ghent, Ostend	128, 36	45, 10	40, 15	1.35	0.51
Sampling rate	512 Hz, 256 Hz	123, 41	43, 12	38, 17	1.35	0.51
Demographics						
Age	[18-65]	34.93 (13.23)	35.62 (13.94)	35.64 (13.45)	0.09	0.92
Sex	Male, Female	53, 111	17, 38	18, 37	1.35	0.51
SES	The same as my peers, Much better than my peers, Better than my peers, Worse than my peers, Much worse than my peers	96, 11, 42, 14, 1	29, 4, 15, 7, 0	37, 2, 14, 2, 0	1.35	0.51
Smoking status	Non-smoker, Former smoker, Smoker	137, 14, 13	44, 7, 4	47, 4, 4	1.35	0.51
BMI	[0-∞]	24.23 (4.12)	23.58 (3.36)	24.76 (4.52)	1.15	0.32
Civil status	Single, In a relationship, Living together, Married, Widow, Divorced	52, 43, 27, 37, 2, 3	19, 12, 10, 12, 0, 2	9, 20, 8, 16, 2, 0	1.35	0.51
Occupation	Student, Working, None	46, 113, 5	17, 37, 1	15, 36, 4	1.35	0.51

Net household income	<€1000/month, €1001-2000/month, €2001-3000/month, €3001-4000/month, €4001-5000/month, €5001-6000/month, >€6000/month	4, 26, 35, 29, 32, 20, 18	3, 7, 10, 13, 12, 2, 8	0, 6, 12, 9, 14, 9, 5	1.35	0.51
Physical activity level (IPAQ)	[0-∞]	2428.01 (3239.22)	2455.1 (2516.75)	2696.93 (4757.28)	0.13	0.88
Residential blue exposure	Every day, A lot, Moderately, Seldom, Never	12, 20, 27, 58, 8	4, 6, 10, 20, 3	5, 9, 9, 14, 6	1.35	0.51
Residential green exposure	Every day, A lot, Moderately, Seldom, Never	46, 59, 43, 16, 3	14, 24, 13, 6, 1	16, 18, 15, 4, 2	1.35	0.51
Residential coastal proximity	0-5km, >5-20km, >20-50km, >50-100km, >100km	14, 8, 64, 64, 14	4, 2, 21, 24, 4	4, 2, 22, 22, 5	1.35	0.51
DASS						
Depression	[0-42]	5.37 (6.23)	6.15 (7.57)	3.93 (4.71)	1.82	0.16
Anxiety	[0-42]	5.00 (4.99)	4.58 (4.77)	4.95 (5.09)	0.15	0.86
Stress	[0-42]	8.59 (6.55)	8.55 (6.75)	8.15 (6.6)	0.09	0.91

2.3. Virtual reality exposures

The virtual reality exposures were 16-minute 360° videos of Belgian beaches, inland urban spaces, and inland green spaces, each with their own ambient sound. Each video consisted of eight 2-minute scenes of these types of environments that transitioned by a 4-second fading to black at the end of the scene and a 4-second fading from black to the subsequent scene. The exposure of the beach showed scenes filmed at different proximities to the sea waterline to cover perspectives from all over the beach and with adjacent dunes or coastal towns; the exposure of the inland green spaces showed scenes of rural farmland, forests, and urban parks; and the exposure of the inland urban spaces showed scenes of city plazas, streets, and shopping areas (supplementary materials section 3.1.2). We consider these locations to be representative for what an individual might encounter during a recreational visit to either of these environments. Similar scenes were shown consecutively. All videos were shot at 5.6K at 30 fps with a 360° camera (GoPro MAX, 2019) mounted at eye level (150 to 160 cm from the ground) on a makeshift combination of tripods (Manfrotto 190, 2013; head replaced by the Three-Way Handle, GoPro, 2014). The camera operator sat in the vicinity of the tripod (10 to 20 meters) to record the sound with a professional shotgun-type microphone with a windshield (RØDE VideoMicro, 2010) that was mounted on a second handheld camera (the Nikon D850, 2017). The videos were shot under clement weather conditions on September 18th, 2020, May 31st, 2021, and June 16th, 2021. There were few visitors present in the environments at the time of filming. The scenes and sound recordings were cut and stitched together, and the tripod and camera operator were masked out with Premiere Pro (Adobe, 2021b) and After Effects (Adobe, 2021a). Figure 16 shows example frames from the scenes in the virtual reality videos. The videos were delivered to the participants through a head-mounted display (Oculus Rift S, 2019) and a noise-cancelling headphone (Sony WH-1000XM3, 2018).

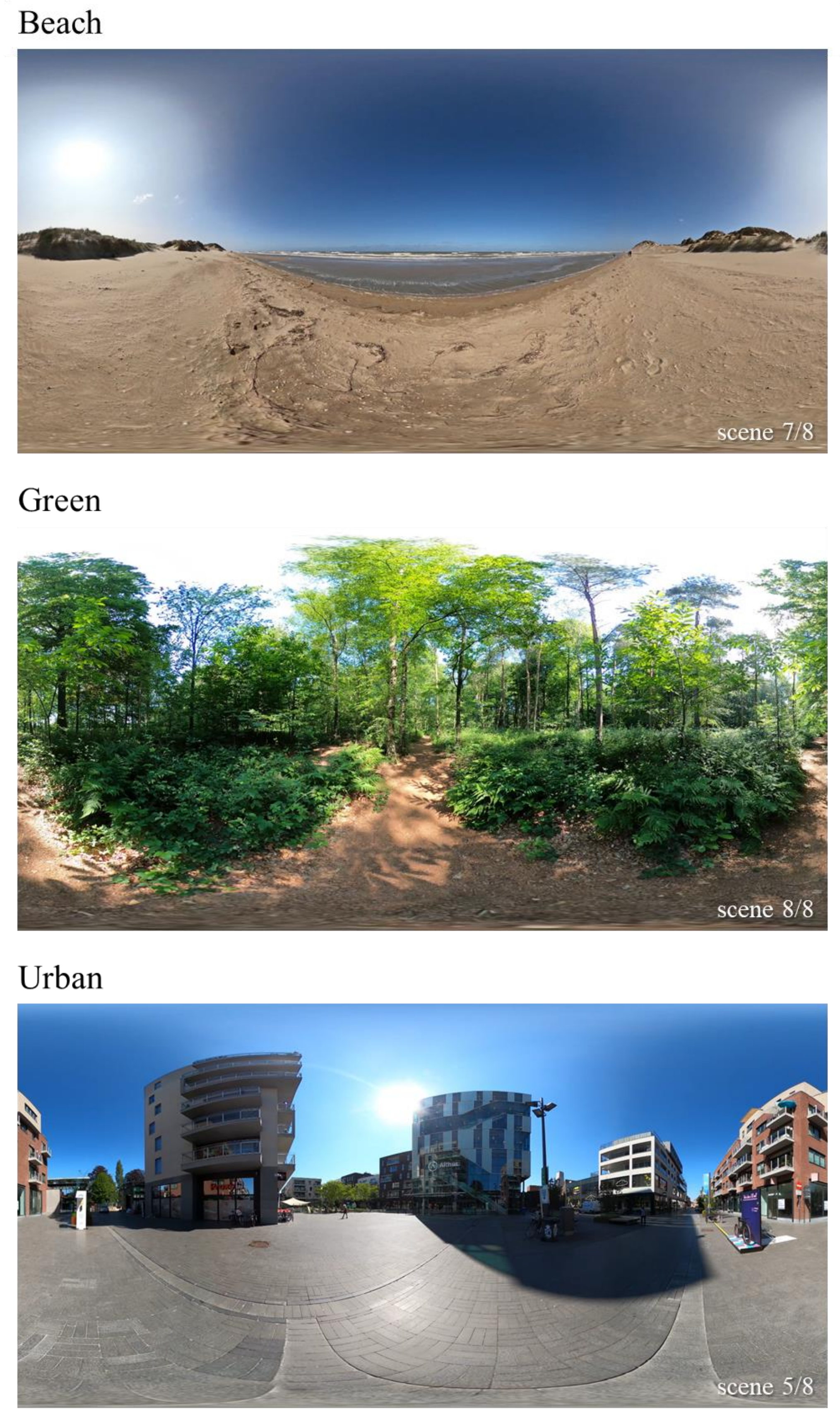

Figure 16: Rectangular projection of spherical example frames from the virtual reality exposures. Scenes are chosen randomly from each exposure and solely serve illustrative purposes.

2.4. Physiological measurements

All autonomic and peripheral parameters were acquired with the NeXus-10 MKII and its accompanying sensors (Mind Media B.V., 2011). The protocol was set up and run in the accompanied software, BioTrace+ (version 2018A1; Mind Media B.V., 2020). The reference electrode was placed on the skin at the middle of the participants' left clavicle. More detailed descriptions of the physiological measurements are available in the supplementary materials section 3.1.3.

2.4.1. Heart rate and HF-HRV

The heart rate captured the overall level of arousal of the participant, and the HF-HRV was used as a proxy for parasympathetic nervous system activity (Berntson et al., 1997; Laborde et al., 2017; Malik et al., 1996; Shaffer & Ginsberg, 2017). Both were derived from an electrocardiogram according to standard guidelines (Laborde et al., 2017; Malik et al., 1996).

The raw signal was analyzed with the PhysioDataToolbox (v0.5.0; Sjak-Shie, 2019), which applied an ECG analyzer and a heart rate variability analyzer to the signal. For each 2-minute section of interest during baseline and exposure, the high frequency power (0.15-0.4 Hz, unit: ms^2) was used for further statistical analyses. Higher HF-HRV values indicate higher parasympathetic nervous system activity.

2.4.2. SCR

The SCR were used as a proxy for sympathetic nervous system activity. It was calculated from a skin conductance signal (Benedek & Kaernbach, 2010).

The raw signals were analyzed in Ledalab (V.3.4.8, Benedek and Kaernbach, 2015). For each 2-minute section of interest during baseline and exposure, the SCR was calculated as the average phasic driver (unit: muS) (Benedek & Kaernbach, 2010, 2015). Higher SCR values are reflective of higher sympathetic nervous system activity.

2.4.3. MAP

The MAP indicates the relative blood flow, which corresponds with many stress-related processes, including activation of autonomic, baro- and chemoreceptors, and endocrine mechanisms that regulate the cardiac output, arterial stiffness, and body temperature (Gopalan & Kirk, 2022). The signal was measured via photoplethysmography (i.e., by a blood volume pulse sensor; Mind Media B.V., 2011).

For each 2-minute section of interest during baseline and exposure, the MAP was extracted with the PhysioDataToolbox (v0.5.0; Sjak-Shie, 2019). For each detected systolic peak and diastolic valley, the MAP was calculated as the addition of the diastolic valley with one third of the difference between the diastolic valley and the systolic peak. Higher MAP values reflect higher blood pressure.

2.4.4. Breathing rate

The breathing rate is regulated by the respiratory center to maintain homeostatic blood parameters (e.g., oxygen depletion; Tipton et al., 2017). Conscious overriding is also possible. The breathing rate was retrieved from recordings of the inhalations and exhalations of the participants with a respiration belt (Mind Media B.V., 2011).

The signal was analyzed in BioTrace+ (version 2018A1, Mind Media B.V., 2020). The respiration rate was averaged for each 2-minute section of interest during baseline and exposure. Higher respiration rates are associated with (mal)adaptive coping with psychological and physiological stress (Tipton et al., 2017).

2.4.5. Muscle tone

Musculus trapezius pars descendens muscle tone reflects the electrical potential of the muscle, which is indicative for the input from the accessory nerve and the reticulospinal tract (Jensen et al., 1993; Johal et al., 2019). It was acquired via an electromyogram by placing a bipolar sensor of an ExG sensor (Mind Media B.V., 2011) along the midpoint of the lead line between the acromion and the spine of the 7th cervical vertebra according to standard guidelines (Jensen et al., 1993; Zipp, 1982).

The signal was analyzed in the PhysioDataToolbox (v0.5.0; Sjak-Shie, 2019). For each 2-minute section of interest during baseline and exposure, the mean value of the filtered, rectified, and smoothed signal was used for statistical analyses. Higher values indicate a higher innervation and a more tensed muscle.

2.5. Self-reported measurements

2.5.1. Positive and negative mood

The participants' positive and negative moods were assessed with the Dutch version of the Positive and Negative Affect Scale (PANAS; Engelen et al., 2006; Watson et al., 1988). This scale has been used extensively in similar previous research (Browning, Shipley, et al., 2020) and has been shown to have good construct validity (J. R. Crawford & Henry, 2004). The internal consistency in this study was good (Cronbach alpha positive mood = 0.92 and Cronbach alpha negative mood = 0.88). More details are available in the supplementary materials section 3.1.4.

2.5.2. Perceived stress

The perceived stress was measured with one question asking the participant "*How relaxed or stressed are you now?*", which was to be scored on an eleven-point Likert scale, with scores ranging from 0 (labelled "*Totally relaxed*"), over 5 (labelled "*Neutral*"), to 10 (labelled "*Totally stressed*"). Such single-item questionnaires have proven their reliability in the past (Verster et al., 2021).

2.5.3. Perceived quality of the environment for stress relief

The quality of the environment for stress relief as perceived by the participants was measured with a single question asking the participant "*At these places, I can relax*".

Answers were to be scored on an eleven-point Likert scale with scores ranging from 0 (labelled "*Totally disagree*", over 5 (labelled "*Neutral*"), to 10 (labelled "*Totally agree*"). This type of questioning focuses on the likelihood of experiencing stress relief as determined by both retrospective and prospective imaginations (Hartig, 2011).

2.6. Stress level in the past week

The stress level in the past week was measured at the onset of the experiment with the stress subscale of the Dutch version of the Depression, Anxiety, and Stress Scale-21 (DASS-21; Lange, 2001). The seven items on the DASS stress subscale are hard to wind down, overreact, have nervous energy, get agitated, are difficult to relax, are intolerant, and are rather touchy, and these items have shown to have good scale reliability (Antony et al., 1998; Osman et al., 2012). The seven scores for stress were summed, multiplied by two, and further analyzed in their continuous formats. The internal consistency was good (Cronbach's alpha DASS-Stress = 0.85).

2.7. Covariates

A questionnaire was used in the online phase of the experiment to assess covariates related to the study design (e.g., order), demographics, environmental exposures, and personality. The covariates were the design period (i.e., the order), the experiment location, the sampling rate for physiological measurements, age, sex, socio-economic status (SES), smoking status, body mass index (BMI), civil status, occupation, net household income, level of physical activity (International Physical Activity Questionnaire; IPAQ), residential blue and green exposure, residential coastal proximity, and the DASS subscales of depression, anxiety, and stress.

2.8. Statistical analyses

The statistical analyses evaluated whether the changes in the physiological and self-reported parameters of stress differed between exposure to beaches vs. urban and green environments and whether these differences varied by level of stress in the past week.

One general linear mixed model was formulated for each physiological and self-reported measure of stress. The parameter of interest was included as sole outcome. Parameters that did not show a normal distribution on their histogram were transformed to a more satisfactory distribution: the negative mood, SCR, and muscle tone were square-root-transformed, and the HF-HRV was log^{10}-transformed. The main predictor in the models was the triple interaction between the type of 'environment' (i.e., beach = reference, green, or urban), 'stress level in the past week' (continuous parameter), and 'time' (for the self-reports: pre = reference and post; for the physiology: b1 = reference, b2, e1, e2, e3, e4, e5, e6, e7, and e8). None of the covariates differed between the three environments (Table 6), so they were not included in the models. The mixed model structure included random intercepts and slopes to let the references and effect estimates vary for each participant and type of environment. To check the models' assumption of normally distributed residuals, the modelled residuals over the fitted values were inspected visually. To check the models' assumption of independent observations relative to the random effects, it was assessed whether the random effects variance was lower than the residual variance.

The unstandardized B-coefficients were extracted to assess the significance of differences from the reference category (i.e., beach, pre/b1) at $\alpha = 0.05$. The estimated marginal means were calculated for visualization. The estimated marginal means were computed for each level of the categorical predictors (i.e., 'time' and 'environment') and for two levels of stress in the past week: at the first and fourth quintiles, which indicate relatively 'low' (DASS-Stress = 2) and 'moderate' (DASS-Stress = 14) stress, respectively (Antony et al., 1998; Figure S 40). The supplementary materials show the ANOVA estimates (section 3.3.1), the B-estimates with p-values corrected for the false discovery rate (section 3.3.2), the estimated marginal means with confidence intervals (section 3.3.3), and the differences between them (section 3.3.4). All analyses were performed in R (R Core Team, 2018), and the general linear mixed models were developed with the package *lme4* (Bates et al., 2015).

3. Results

3.1. Physiological parameters

Each virtual environment caused a lower heart rate and HF-HRV and a higher SCR, MAP, breathing rate, and muscle tone (Figure 17, Table 7). Beaches resulted in smaller increases in the breathing rate compared to the urban environments (e.g., $B_{Urban:e1} = 1.926 \pm 0.879$, $p \leq 0.05$) and smaller increases in the SCR compared to the green environments (i.e., from e1 to e8; e.g., $B_{Green:e1} = 0.083 \pm 0.032$, $p \leq 0.01$; Figure 17, Table 7). The smaller increases in the SCR were less pronounced when the level of stress in the past week was higher (e.g., $B_{Green:e1:DASS\text{-}Stress} = -0.006 \pm 0.003$, $p \leq 0.05$). Urban environments resulted in intermediate SCR values.

The muscle tone showed complex patterns that were distinct per environment and per level of stress in the past week. More specifically, in the case of low levels of stress in the past week, beaches caused an increase in the upper trapezius muscle tone ($B_{e1} = 0.014 \pm 0.005$, $p \leq 0.01$), and green environments did not (e.g., at $B_{Green:e1} = -0.024 \pm 0.009$, $p \leq 0.01$). In the case of moderate levels of stress in the past week, beaches did not result in a higher upper trapezius muscle tone, but green environments did (e.g., at $B_{Green:e1:DASS\text{-}Stress} = 0.003 \pm 0.001$, $p \leq 0.001$). These patterns occurred only during the first six minutes of the exposures.

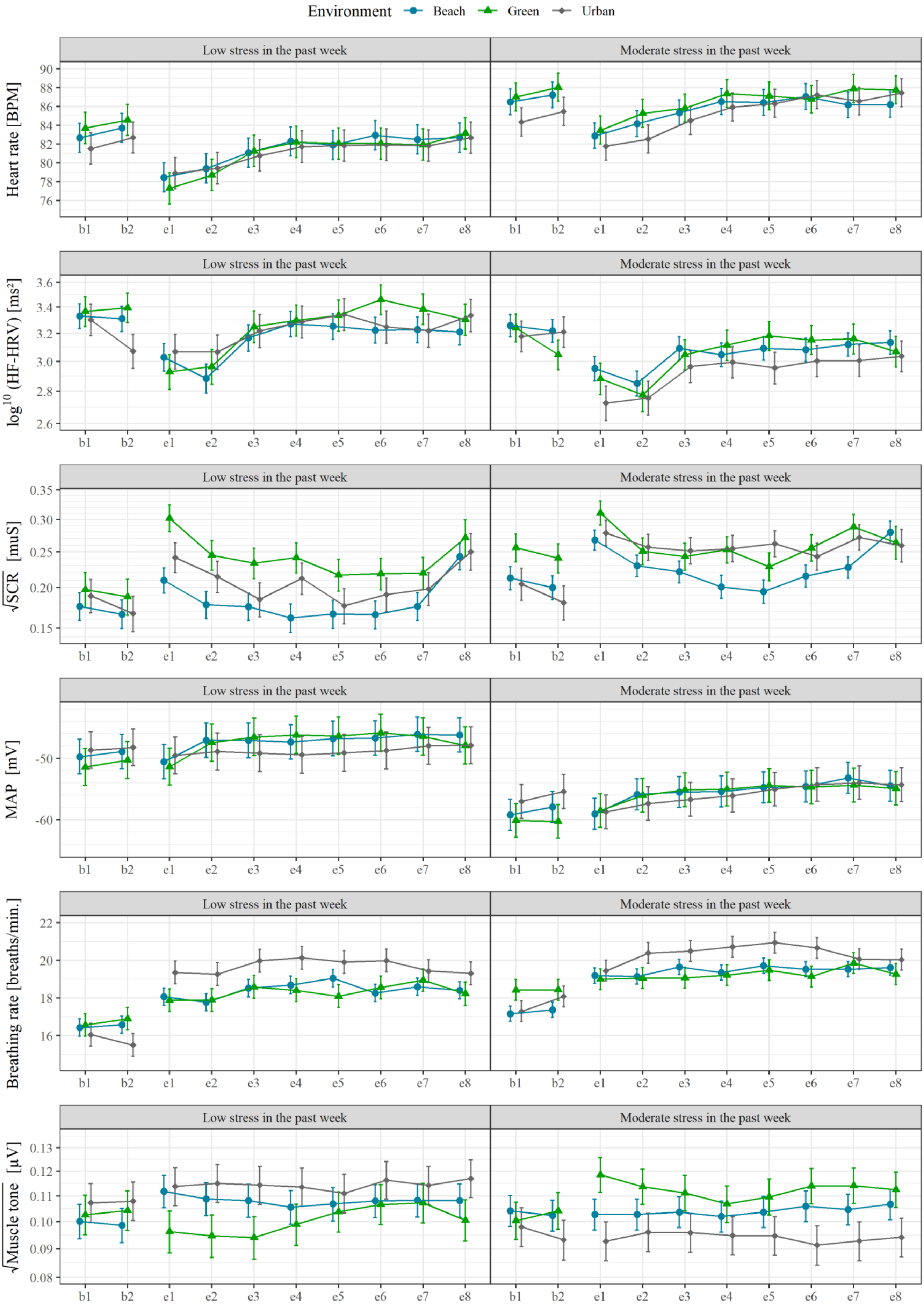
Environment
Beach
Green
Urban
Low stress in the past week
Moderate stress in the past week
Heart rate [BPM]
log10 (HF-HRV) [ms²]
√SCR [muS]
MAP [mV]
Breathing rate [breaths/min.]
√Muscle tone [µV]
b1
b2
e1
e2
e3
e4
e5
e6
e7
e8

Figure 17: Visualized estimated marginal means and standard error of the physiological parameters of stress for each type of exposure (i.e., beach, green, and urban, see legend on top), and for participants who had a relatively ‘low’ and ‘moderate’ level of stress in the past week (i.e., DASS-Stress value at Q1 = 1 and at Q4 = 14, respectively). Significances of changes are described in the main manuscript. Parameters that were transformed (i.e., HF-HRV, SCR, and Muscle tone) during modelling were not back-transformed for statistical accuracy.
Abbreviations: HF-HRV = high frequency heart rate variability; SCR = skin conductance response; BPM = beats per minute; MAP = mean arterial pressure

Table 7: B-coefficients and standard errors (SE) of the physiological parameters of stress from the general linear mixed models. Each column depicts the results from the model on that outcome parameter. The intercepts represent the predicted values of the outcome parameter for the beach at b1 at the mean value of DASS-Stress (continuous variable). The B-coefficients of the categorical main effects (i.e., 'green', 'urban', 'b2', and 'e1' to 'e8') indicate the changes from the intercept to these predictor levels, and those of the continuous main effects (i.e., 'DASS-Stress') indicate their slopes, while all other predictors are held constant. The B-coefficients of the interaction terms (i.e., those with ':') indicate the changes from the intercept (i.e., for categorical predictors) or slopes (i.e., for those with DASS-Stress) above those of the main effects. As such, all coefficients are relative to the effects of the 'beach'. B-coefficients are unstandardized.
Significances: '.': p ≤ 0.1; '*': p ≤ 0.05; '**': p ≤ 0.01; '***': p ≤ 0.001.
Abbreviations: HF-HRV = high frequency heart rate variability; SCR = skin conductance response; MAP = mean arterial pressure.
[a] N-values represent the number of individual observations or data points on which the model was based.

	Heart rate		log10(HF-HRV)		√(SCR)		MAP		Breathing rate		√(Muscle tone)	
	N[a] = 2269		N[a] = 2218		N[a] = 2120		N[a] = 2371		N[a] = 2445		N[a] = 2322	
Coefficient	B ± SE		B ± SE		B ± SE		B ± SE		B ± SE		B ± SE	
Intercept (Beach, b1)	82.034 ± 1.767	***	3.343 ± 0.110	***	0.170 ± 0.020	***	-48.142 ± 3.242	***	16.311 ± 0.533	***	0.099 ± 0.007	***
Green	1.116 ± 0.979		0.044 ± 0.110		0.018 ± 0.024		-1.820 ± 1.739		-0.063 ± 0.624		0.004 ± 0.007	
Urban	-0.979 ± 1.015		-0.021 ± 0.118		0.017 ± 0.022		0.875 ± 1.734		-0.460 ± 0.635		0.009 ± 0.007	
b2	1.110 ± 0.702		-0.017 ± 0.081		-0.009 ± 0.016		0.774 ± 1.220		0.145 ± 0.449		-0.001 ± 0.005	
e1	-4.330 ± 0.710	***	-0.300 ± 0.081	***	0.031 ± 0.015	*	-0.988 ± 1.230		1.569 ± 0.449	***	0.014 ± 0.005	**
e2	-3.401 ± 0.710	***	-0.453 ± 0.081	***	≤0.001 ± 0.015		2.549 ± 1.230	*	1.238 ± 0.449	**	0.010 ± 0.005	*
e3	-1.638 ± 0.710	*	-0.163 ± 0.081	*	-0.002 ± 0.015		2.456 ± 1.230	*	2.026 ± 0.449	***	0.009 ± 0.005	*
e4	-0.477 ± 0.710		-0.036 ± 0.081		-0.014 ± 0.015		2.161 ± 1.230	.	2.273 ± 0.449	***	0.007 ± 0.005	
e5	-0.880 ± 0.710		-0.064 ± 0.082		-0.008 ± 0.015		2.706 ± 1.230	*	2.628 ± 0.449	***	0.008 ± 0.005	.
e6	0.223 ± 0.710		-0.095 ± 0.082		-0.012 ± 0.015		2.770 ± 1.230	*	1.748 ± 0.449	***	0.009 ± 0.005	.
e7	-0.159 ± 0.710		-0.097 ± 0.082		-0.002 ± 0.016		3.222 ± 1.230	**	2.133 ± 0.450	***	0.009 ± 0.005	*
e8	0.062 ± 0.710		-0.118 ± 0.082		0.068 ± 0.019	***	3.303 ± 1.230	**	1.896 ± 0.452	***	0.009 ± 0.005	.
DASS-Stress	0.318 ± 0.154	*	-0.006 ± 0.010		0.003 ± 0.002	.	-0.790 ± 0.294	**	0.061 ± 0.048		≤0.001 ± 0.001	
Green:b2	-0.270 ± 1.347		0.083 ± 0.152		0.001 ± 0.033		0.585 ± 2.391		0.259 ± 0.863		0.003 ± 0.009	

Coefficient	Heart rate Nª = 2269 B ± SE		log10(HF-HRV) Nª = 2218 B ± SE	√(SCR) Nª = 2120 B ± SE		MAP Nª = 2371 B ± SE	Breathing rate Nª = 2445 B ± SE		√(Muscle tone) Nª = 2322 B ± SE	
Urban:b2	0.074 ± 1.400		-0.257 ± 0.163	-0.013 ± 0.030		-0.532 ± 2.395	-0.922 ± 0.879		0.003 ± 0.009	
Green:e1	-2.554 ± 1.378	.	-0.150 ± 0.155	0.083 ± 0.032	**	0.774 ± 2.444	-0.127 ± 0.863		-0.024 ± 0.009	**
Urban:e1	1.695 ± 1.412		0.105 ± 0.163	0.018 ± 0.030		0.240 ± 2.411	1.926 ± 0.879	*	-0.005 ± 0.009	
Green:e2	-2.133 ± 1.378		0.061 ± 0.155	0.057 ± 0.031	.	1.395 ± 2.444	0.214 ± 0.870		-0.022 ± 0.009	*
Urban:e2	1.269 ± 1.412		0.249 ± 0.163	0.021 ± 0.030		-2.766 ± 2.411	1.993 ± 0.879	*	-0.001 ± 0.009	
Green:e3	-0.996 ± 1.378		0.059 ± 0.155	0.046 ± 0.031		2.433 ± 2.444	0.228 ± 0.870		-0.021 ± 0.009	*
Urban:e3	0.740 ± 1.412		0.102 ± 0.164	-0.012 ± 0.030		-3.115 ± 2.411	2.013 ± 0.879	*	-0.001 ± 0.009	
Green:e4	-1.316 ± 1.378		-0.022 ± 0.156	0.066 ± 0.031	*	3.088 ± 2.444	-0.246 ± 0.870		-0.012 ± 0.009	
Urban:e4	0.438 ± 1.412		0.049 ± 0.164	0.033 ± 0.030		-3.202 ± 2.411	1.914 ± 0.879	*	0.001 ± 0.009	
Green:e5	-1.048 ± 1.378		0.037 ± 0.155	0.035 ± 0.031		2.253 ± 2.444	-1.009 ± 0.870		-0.008 ± 0.009	
Urban:e5	0.927 ± 1.412		0.150 ± 0.164	-0.016 ± 0.030		-3.545 ± 2.411	1.252 ± 0.879		-0.003 ± 0.009	
Green:e6	-2.093 ± 1.378		0.219 ± 0.155	0.037 ± 0.031		2.814 ± 2.444	0.470 ± 0.870		-0.006 ± 0.009	
Urban:e6	-0.233 ± 1.412		0.061 ± 0.164	0.008 ± 0.030		-3.310 ± 2.411	2.275 ± 0.879	**	0.003 ± 0.009	
Green:e7	-2.046 ± 1.381		0.130 ± 0.156	0.023 ± 0.032		1.632 ± 2.444	0.418 ± 0.870		-0.006 ± 0.009	
Urban:e7	0.146 ± 1.412		0.031 ± 0.164	0.002 ± 0.030		-2.917 ± 2.411	1.348 ± 0.879		≤0.001 ± 0.009	
Green:e8	-0.837 ± 1.390		0.074 ± 0.157	0.017 ± 0.039		-0.076 ± 2.460	-0.093 ± 0.885		-0.013 ± 0.009	
Urban:e8	0.775 ± 1.412		0.182 ± 0.166	-0.005 ± 0.037		-2.843 ± 2.411	1.440 ± 0.881		0.003 ± 0.009	
Green:DASS-Stress	-0.043 ± 0.090		-0.004 ± 0.010	0.002 ± 0.002		0.064 ± 0.160	0.095 ± 0.058		-0.001 ± 0.001	
Urban:DASS-Stress	-0.083 ± 0.096		-0.004 ± 0.011	-0.002 ± 0.002		0.094 ± 0.168	0.042 ± 0.059		-0.001 ± 0.001	.
b2:DASS-Stress	-0.026 ± 0.063		-0.002 ± 0.007	≤0.001 ± 0.001		0.037 ± 0.112	0.005 ± 0.041		≤0.001 ± ≤0.001	
e1:DASS-Stress	0.053 ± 0.063		≤0.001 ± 0.007	0.002 ± 0.001		0.081 ± 0.112	0.032 ± 0.041		-0.001 ± ≤0.001	**

Coefficient	Heart rate N^a = 2269 B ± SE	log^{10}(HF-HRV) N^a = 2218 B ± SE	√(SCR) N^a = 2120 B ± SE	MAP N^a = 2371 B ± SE	Breathing rate N^a = 2445 B ± SE	√(Muscle tone) N^a = 2322 B ± SE
e2:DASS-Stress	0.077 ± 0.063	0.003 ± 0.007	0.001 ± 0.001	0.056 ± 0.112	0.053 ± 0.041	-0.001 ± ≤0.001 *
e3:DASS-Stress	0.036 ± 0.063	≤0.001 ± 0.007	0.001 ± 0.001	0.090 ± 0.112	0.033 ± 0.041	-0.001 ± ≤0.001 .
e4:DASS-Stress	0.037 ± 0.063	-0.013 ± 0.007 .	≤0.001 ± 0.001	0.117 ± 0.112	-0.006 ± 0.041	-0.001 ± ≤0.001
e5:DASS-Stress	0.058 ± 0.063	-0.007 ± 0.007	-0.001 ± 0.001	0.125 ± 0.112	-0.006 ± 0.041	-0.001 ± ≤0.001
e6:DASS-Stress	0.025 ± 0.063	-0.006 ± 0.007	0.001 ± 0.001	0.132 ± 0.112	0.044 ± 0.041	-0.001 ± ≤0.001
e7:DASS-Stress	-0.012 ± 0.063	-0.003 ± 0.007	0.001 ± 0.001	0.200 ± 0.112 .	0.016 ± 0.041	-0.001 ± ≤0.001
e8:DASS-Stress	-0.024 ± 0.063	≤0.001 ± 0.007	≤0.001 ± 0.002	0.103 ± 0.112	0.039 ± 0.041	≤0.001 ± ≤0.001
Green:b2:DASS-Stress	0.041 ± 0.123	-0.017 ± 0.014	≤0.001 ± 0.003	-0.144 ± 0.220	-0.033 ± 0.080	≤0.001 ± 0.001
Urban:b2:DASS-Stress	0.022 ± 0.132	0.024 ± 0.016	≤0.001 ± 0.003	0.060 ± 0.232	0.108 ± 0.081	≤0.001 ± 0.001
Green:e1:DASS-Stress	0.188 ± 0.125	0.007 ± 0.014	-0.006 ± 0.003 *	0.050 ± 0.223	-0.095 ± 0.080	0.003 ± 0.001 ***
Urban:e1:DASS-Stress	-0.048 ± 0.130	-0.018 ± 0.015	≤0.001 ± 0.003	-0.149 ± 0.228	-0.128 ± 0.081	≤0.001 ± 0.001
Green:e2:DASS-Stress	0.195 ± 0.125	-0.008 ± 0.014	-0.006 ± 0.003 *	-0.045 ± 0.223	-0.111 ± 0.080	0.003 ± 0.001 **
Urban:e2:DASS-Stress	-0.054 ± 0.130	-0.019 ± 0.015	0.001 ± 0.003	-0.066 ± 0.228	-0.062 ± 0.081	≤0.001 ± 0.001
Green:e3:DASS-Stress	0.068 ± 0.125	-0.006 ± 0.014	-0.005 ± 0.003 .	-0.082 ± 0.223	-0.147 ± 0.080 .	0.002 ± 0.001 **
Urban:e3:DASS-Stress	0.040 ± 0.130	-0.011 ± 0.015	0.004 ± 0.003	-0.019 ± 0.228	-0.092 ± 0.081	≤0.001 ± 0.001
Green:e4:DASS-Stress	0.117 ± 0.125	0.008 ± 0.014	-0.004 ± 0.003	-0.127 ± 0.223	-0.082 ± 0.080	0.001 ± 0.001 .

Coefficient	Heart rate $N^a = 2269$ B ± SE		log10(HF-HRV) $N^a = 2218$ B ± SE	√(SCR) $N^a = 2120$ B ± SE		MAP $N^a = 2371$ B ± SE	Breathing rate $N^a = 2445$ B ± SE		√(Muscle tone) $N^a = 2322$ B ± SE	
Urban:e4:DASS-Stress	0.080 ± 0.130		-0.001 ± 0.015	0.002 ± 0.003		0.025 ± 0.228	-0.048 ± 0.081		≤0.001 ± 0.001	
Green:e5:DASS-Stress	0.088 ± 0.125		0.005 ± 0.014	-0.003 ± 0.003		-0.073 ± 0.223	-0.035 ± 0.080		0.001 ± 0.001	
Urban:e5:DASS-Stress	0.079 ± 0.130		-0.015 ± 0.015	0.007 ± 0.003	*	0.076 ± 0.228	-0.010 ± 0.081		≤0.001 ± 0.001	
Green:e6:DASS-Stress	0.092 ± 0.125		-0.009 ± 0.014	-0.003 ± 0.003		-0.142 ± 0.223	-0.152 ± 0.080	.	0.001 ± 0.001	
Urban:e6:DASS-Stress	0.183 ± 0.130		-0.004 ± 0.015	0.002 ± 0.003		0.102 ± 0.228	-0.090 ± 0.081		-0.001 ± 0.001	
Green:e7:DASS-Stress	0.232 ± 0.127	.	-0.005 ± 0.014	≤0.001 ± 0.003		-0.136 ± 0.223	-0.097 ± 0.080		0.001 ± 0.001	.
Urban:e7:DASS-Stress	0.171 ± 0.130		-0.005 ± 0.015	0.004 ± 0.003		-0.004 ± 0.228	-0.067 ± 0.081		≤0.001 ± 0.001	
Green:e8:DASS-Stress	0.134 ± 0.127		-0.009 ± 0.014	-0.005 ± 0.003		0.041 ± 0.223	-0.109 ± 0.081		0.002 ± 0.001	*
Urban:e8:DASS-Stress	0.185 ± 0.130		-0.014 ± 0.016	≤0.001 ± 0.003		0.056 ± 0.228	-0.081 ± 0.081		-0.001 ± 0.001	

3.2. Self-reported parameters

Beaches scored better than urban environments on all of the measured self-reported parameters of stress. More specifically, beaches decreased the negative mood and perceived stress under moderate levels of stress in the past week ($B_{Post:DASS-Stress}$ = -0.009 ± 0.003, p ≤ 0.01), while the urban environments increased these parameters under both low and moderate stress in the past week (Figure 18, Table 8), and the green environments did not impact these parameters under moderate stress in the past week. The positive mood decreased in response to urban environments under moderate levels of stress in the past week ($B_{Urban:Post:DASS-Stress}$ = -0.036 ± 0.012, p ≤ 0.01) and urban environments showed a much lower perceived quality for relaxation than beaches and green environments (B_{Urban} = -4.5 ± 0.5, p ≤ 0.001). Generally, participants with a higher stress level in the past week displayed worse scores for positive mood, negative mood, and perceived stress.

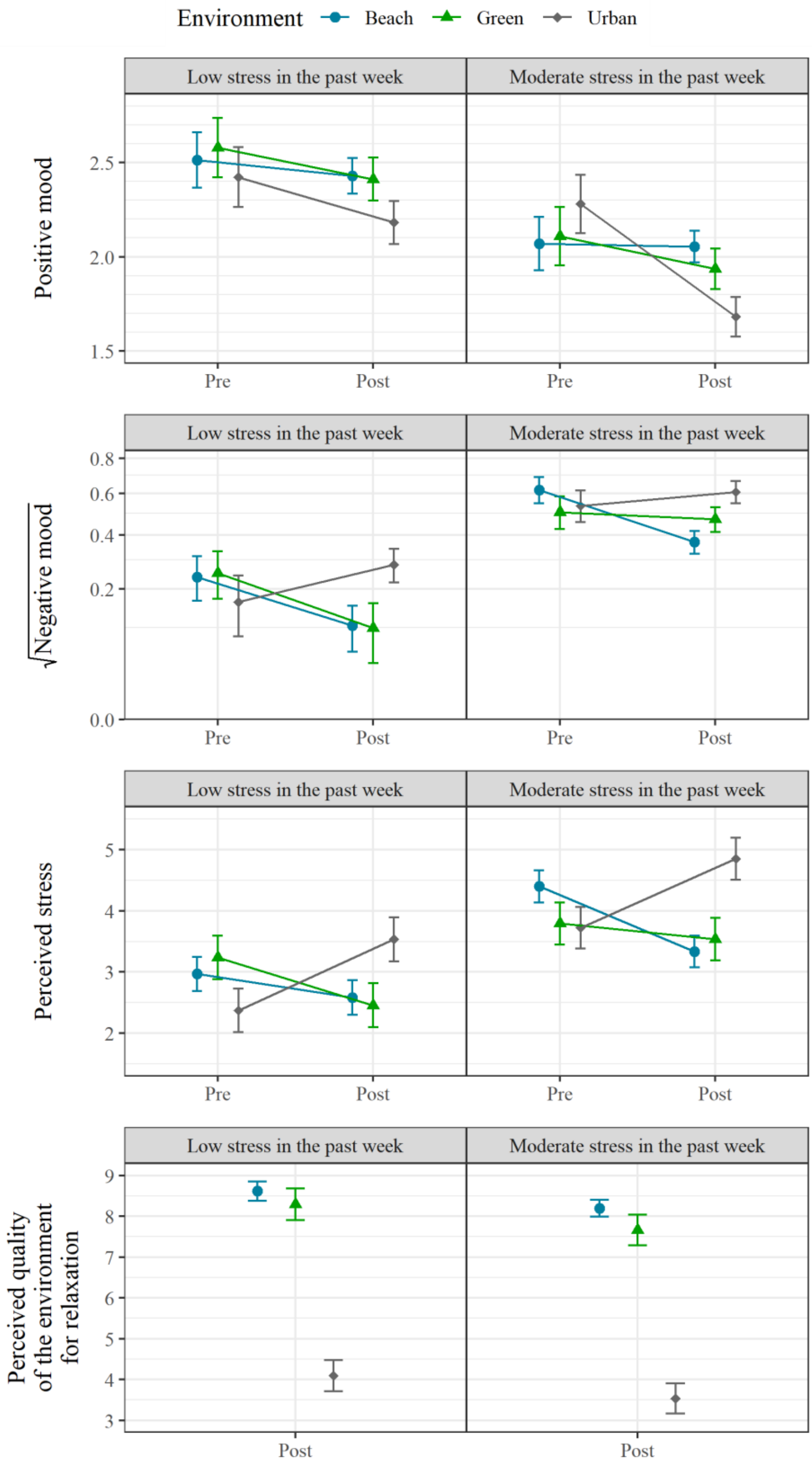

Figure 18: Visualized estimated marginal means and standard errors of the self-reported parameters of stress for each type of exposure (i.e., beach, green, and urban, see legend on top), and for participants who had a relatively 'low' (DASS-Stress value at Q1 = 1) and 'moderate' (DASS-Stress value at Q4 = 14) level of stress in the past week. Significances of changes are described in the main manuscript. Parameters that were transformed during modelling (i.e., negative mood) are plotted with their transformed values on the transformed axes.

Table 8: B-coefficients and standard errors (SE) of the self-reported parameters of stress from the general linear mixed models. Each column depicts the results from the model on that parameter. The intercepts represent the predicted values of the outcome parameter for the beach before the exposure ('pre') at the mean value of DASS-Stress (continuous variable). The B-coefficients of the categorical main effects (i.e., 'green', 'urban', and 'post') indicate the changes from the intercept to these predictor levels, and those of the continuous main effects (i.e., 'DASS-Stress') indicate their slopes, while all other predictors are held constant. The B-coefficients of the interaction terms (i.e., those with ':') indicate the changes from the intercept (categorical predictors only) or slopes (i.e., with DASS-Stress) above those of the main effects. As such, all coefficients are relative to the effects of the 'beach'. B-coefficients are unstandardized.
Significances: '.': p ≤ 0.1; '*': p ≤ 0.05; '**': p ≤ 0.01; '***': p ≤ 0.001.
[a] N-values represent the number of individual observations or data points on which the model was based.

	Positive mood		√(Negative mood)		Perceived stress		Perceived quality of the environment for relaxation	
	N[a] = 541		N[a] = 541		N[a] = 541		N[a] = 269	
Coefficient	B ± SE		B ± SE		B ± SE		B ± SE	
Intercept (Beach, Pre)	2.588 ± 0.154	**	0.176 ± 0.076		2.732 ± 0.305	***	8.685 ± 0.266	***
Green	0.069 ± 0.095		0.034 ± 0.055		0.415 ± 0.347		-0.285 ± 0.495	
Urban	-0.142 ± 0.095		-0.076 ± 0.055		-0.583 ± 0.351	.	-4.497 ± 0.504	***
Post	-0.097 ± 0.122		-0.117 ± 0.047	.	-0.273 ± 0.237		/	
DASS-Stress	-0.037 ± 0.008	***	0.032 ± 0.004	***	0.119 ± 0.023	***	-0.035 ± 0.024	
Green:Post	-0.069 ± 0.123		-0.057 ± 0.071		-0.597 ± 0.452		/	
Urban:Post	-0.084 ± 0.124		0.243 ± 0.072	***	1.440 ± 0.460	**	/	
Green:DASS-Stress	-0.002 ± 0.009		-0.011 ± 0.005	*	-0.073 ± 0.033	*	-0.018 ± 0.046	
Urban:DASS-Stress	0.025 ± 0.009	**	-0.001 ± 0.005		-0.006 ± 0.033		-0.012 ± 0.047	
Post:DASS-Stress	0.006 ± 0.006		-0.009 ± 0.003	**	-0.057 ± 0.022	**	/	
Green:Post:DASS-Stress	-0.006 ± 0.011		0.019 ± 0.007	**	0.100 ± 0.042	*	/	
Urban:Post:DASS-Stress	-0.036 ± 0.012	**	0.006 ± 0.007		0.054 ± 0.043		/	

4. Discussion

4.1. Main results

The results of this study demonstrate that beaches are more effective than urban and green environments in relaxing the physiological pathways of stress. First and foremost, beaches induced a lower increase in the breathing rate than urban environments. To our knowledge, no previous study has compared the effects of beaches and urban environments on the physiology of breathing. Importantly, breathing unconsciously is regulated by both the sympathetic and parasympathetic nervous systems' activity to maintain homeostatic blood parameters (e.g., prevent oxygen depletion; Tipton et al., 2017). Inversely, breathing slower also influences respiratory, cardiovascular, autonomic, cognitive, and emotional processes that can have far-reaching benefits for health (see Russo et al., 2017, and Zaccaro et al., 2018, for the full range of benefits). Thus, the fact that many people who are exposed to beaches report benefits for health and well-being may be caused by these people relatively slowing down their breathing (Ashbullby et al., 2013; S. L. Bell et al., 2015; Hipp & Ogunseitan, 2011; Hooyberg, Michels, et al., 2022; Peng et al., 2016b, 2016a; Severin et al., 2022; White et al., 2010; Wyles et al., 2016). Noteworthy is that these benefits of beaches did not differ from the effects of green environments.

The results of this study strengthen the evidence from the literature that shows that beaches downregulate the sympathetic nervous system, and have no influence on the parasympathetic nervous system or the overall cardiovascular arousal. More specifically, Anderson et al. (2017) found that watching virtual remote beaches decreased skin conductance levels more than the urban control, indicating that beaches downregulate the sympathetic nervous system activity. From our visualizations, it also seemed that beaches had a more downregulating force on the SCR relative to urban environments, but these differences were not statistically significant, unfortunately. The parasympathetic responses to beaches seem to be negligible, because our study and previous studies found that the HF-HRV responses to beaches vs. urban environments did not differ (Anderson et al., 2017; Triguero-Mas et al., 2017; White et al., 2015).[4] Apparently, beaches also do not decrease the overall cardiovascular arousal, because neither this study nor previous studies found changes in the heart rate or MAP (Anderson et al., 2017; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015).

To our knowledge, this is also the first study that analytically compares the effects of beaches with those of green environments on physiological outcomes. Most strikingly,

[4] Note that some of these studies used the low-frequency to high-frequency heart rate variability ratio (LF/HF) as an index of the autonomic balance or the relative power of the sympathetic over the parasympathetic nervous system activity (Triguero-Mas et al., 2017; Vert et al., 2020). However, using the LF/HF ratio as an index for the autonomic balance has been contested (Billman, 2013). So, we did not calculate these indices in this study nor do we make inferences from these measures when interpreting the results of these studies, and we focus on those indices that reflect the pure parasympathetic (i.e., HF-HRV) or pure sympathetic (i.e., SCR) nervous system activity (Benedek & Kaernbach, 2010; Berntson et al., 1997; Laborde et al., 2017; Laine et al., 2009; Malik et al., 1996).

beaches caused smaller increases in SCR than green environments, meaning that beaches seem to be more efficient in calming the central nervous system in driving the sudomotor activity of the sympathetic nervous system (Christopoulos et al., 2019; Laborde et al., 2017). This effect was less pronounced under moderate stress, potentially because participants with moderate stress already had high SCR. As such, the large increase in response to green environments was limited due to a ceiling effect, while the smaller increase in response to beaches was not (Figure 17). Also meaningful was the fact that beaches decreased the negative mood and perceived stress under both low and moderate stress, but green exposures only reduced these parameters under low stress. Crucially, this suggests that people who had a moderate stress level in the past week would rather benefit from a (virtual) exposure to a beach than a green environment. A final, but less explicable, result was that the upper trapezius muscle tone increased in response to beaches under low but not moderate stress, while green environments increased the upper trapezius muscle tone under moderate but not low stress. During involuntary contraction, the upper trapezius muscle tone displays the activity of the accessory nerve (i.e., the eleventh cranial nerve) and the reticulospinal tract, which is responsible for locomotion and postural movement (Johal et al., 2019; Marker et al., 2017; Paulsen & Waschke, 2011). A higher muscle tone is generally associated with more mental stress (Marker et al., 2017; Wijsman et al., 2013). Previous studies that evaluated the effects of nature on muscle tone have always focused on the frontalis muscle on the forehead, which became less tensed in response to green exposures (Largo-Wight et al., 2016; Ulrich et al., 1991). Given the complexity of our results and the absence of any previous studies on upper trapezius muscle responses to beaches, we argue that further research is necessary to disentangle how somatic excitations, such as those of the upper trapezius or frontalis muscles, may differ depending on the type of exposed environment and the stress-level of the exposed individual. In sum, each of the many visual and auditory features that are unique to beaches may have contributed to their beneficial effects on the breathing rate, sympathetic nervous system activity, and subjective ratings of stress and mood (e.g., presence of sand, sky visibility, colors; Cracknell, 2019; Hooyberg et al., 2022).

4.2. Limitations and strengths

This study is unique compared to the previous literature, because no previous study has assessed both cardiovascular, respiratory, and muscular pathways of stress in response to beaches, while making the comparison with urban and green environments and while considering the level of stress in the past week. We also deviated from the convention of considering the urban exposure as the control (Browning et al., 2021; Hartig et al., 2014). Instead, we considered the beach as the control to have all our participants exposed to the environment of prime interest and to result in maximal power for the comparison with both the urban and green environments.

This study exploited the natural variation of stress in the past week from a relatively large and relatively representative sample from the Flemish population (N = 164), which allowed us to gain societally relevant insights. A potential downside of this is that the recruited participants also had divergent demographic and health characteristics, which may have resulted in relatively large uncertainties on the estimated effect sizes compared to when a more confined population would have been sampled. Since there were few participants who reported a 'high' level of stress in the previous week, the visualizations of our analyses were restricted to 'low' and 'moderate' levels of precedent stress. Nevertheless, the acquired data revealed that the effects of beaches and green spaces differ when the level of precedent stress increases, and that the self-reported benefits of green environments did not hold under moderate levels of precedent stress.

The use of virtual reality has led to consistent physiological reactions at the onset of the exposures. At the start of the virtual reality exposures, there was an apparent downregulation of the parasympathetic nervous system and an upregulation of the sympathetic nervous system. The use of virtual reality may also have caused beaches not to improve the positive mood (see Browning, Mimnaugh, et al., 2020 for the reasons why; Browning, Shipley, et al., 2020; Elliott et al., 2015, 2018; Hooyberg et al., 2022; White et al., 2010, 2014, 2020; Wyles et al., 2016). Also, it seems that the 16-minute virtual reality exposures used in this study did not provide additional benefits over the often used shorter exposures of 10 minutes (Browning, Mimnaugh, et al., 2020; Calogiuri & Elliott, 2017; Chirico & Gaggioli, 2019). From 12 minutes onwards, there was even heightened sympathetic activity, which potentially reflected feelings of frustration, agitation, and impatience towards the end. Nevertheless, virtual reality still proved to be a valuable tool for exposing the large number of participants to the different environments while blinding them to the environment they were going to be exposed to. It also ensured a higher level of immersion compared to alternative flat-screen-type exposures and excluded the undesired effects of physical activity and sensory inputs otherwise found in real environments (Anderson et al., 2017; Browning et al., 2021; Browning, Mimnaugh, et al., 2020).

4.3. Avenues for future research

To expand the knowledge base on the effects of beaches, future research should replicate the results of this study on different populations and in different contexts (e.g., not with virtual reality), while tackling the limitations of this study and drawing from its strengths. While doing so, it is crucial to measure indices of both parasympathetic, sympathetic, and somatic physiological pathways, because the results of this study show that measuring only one of these may lead to incomplete interpretations. Furthermore, a number of new avenues for future research seem societally and scientifically relevant. Firstly, since stress-reduction theory and attention restoration theory predict that emotional responses to outdoor environments should coincide with cognitive changes (R. Kaplan & Kaplan, 1989; Ulrich et al., 1991), future research should test the effects of coastal environments also on cognitive performance, brain functioning, (visual) attention, and neurological and hormonal processes in the brain. While this study mainly focused on autonomically and somatically driven changes, understanding the full stress-reactivity to beaches will also require measurements of the hypothalamic–pituitary–adrenal axis, such as cortisol. Additionally, there exist many types of coastal environments that differ in perceived restorativeness (Hooyberg, Michels, et al., 2022), and future research should validate whether those differences also translate into different psychophysiological reactions. Some coastal environments may also attract different visitors with different habitus, and disentangling the sociological variation behind these visits might help to explain why some people may benefit more or less from the coast and specific coastal environments than others. In this respect, the moderating effects of other pathologies than perceived levels of stress in the past week should be assessed, and those that drive the most differential effects should be identified. For example, the benefits of the coast may differ depending on the severity of personality traits, symptoms of anxiety, depression, rumination, or burnout, or even beliefs about the health benefits of the coast. Interestingly, the acquired data for this study allows to perform additional analyses on character-specific responses to the exposed environments other than the stress level in the past week (i.e., by age, gender, or socio-economic status).

5. Conclusion

This study strengthens the evidence about how beaches impact physiological and self-reported parameters of stress differently than urban and green environments. We demonstrate that beaches slow down the breathing rate more than urban environments and downregulate the sympathetic nervous system more than green environments. The effects of beaches on the heart rate, HF-HRV, and MAP were negligible, which adds to a consistent pattern in the extant literature (Anderson et al., 2017; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015). The upper trapezius muscle tone reacted differently to beaches and green environments depending on the stress level in the past week. Beaches reduced the negative mood (not positive mood) and self-rated stress under moderate levels of initial stress, while green environments did not improve these parameters under moderate stress, and urban environments relatively worsened all self-reported parameters of stress. Overall, the results of this study illustrate that exposure to (virtual) beaches improves health and well-being by providing psychological and physiological restoration. Future research should focus on further strengthening the evidence base by replicating this study's results and testing the effects on populations with different socio-demographic and health characteristics and with different modes of exposure.

6. Acknowledgements

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Survey data linking coastal visit behaviors to socio-demographic and health characteristics

Adapted from (Hooyberg et al., 2024)

Abstract

Coastal destinations are highly popular for leisure, yet the effects of spending time at the coast on mental and physical health have remained underexplored. To accelerate the research about the effects of the coast on health, we compiled a dataset from a survey on a sample (N = 1939) of the adult Flemish population about their visits to the Belgian coast. The survey queried the respondents' number of day visits and/or longer stays per season in the previous year and the following characteristics of their visits: how often they performed specific activities, which of the 14 municipal seaside resorts they visited, who they were with, what they mentally and physically experienced, and what reasons they had for not visiting the coast more often. The respondents' geo-demographic (including residential proximity to the coast), socio-economic, and health profile was also collected. We anticipate that investigations on the data will increase our understanding about the social structuring of coastal visits and give context to the effects of the coast on human health.

Keywords

Coastal visits, Survey, Health, Socio-Economic Status, Demography

1. Background & Summary

More than half of all tourism involves a coastal or marine destination, and blue tourism annually accounts for 4.6 trillion US dollar or 5.2% of the global gross domestic product (Northrop et al., 2022). Coastal destinations have been attractive for centuries because of their beneficial effects on mental and physical health (Hooyberg et al., 2020; Wheeler et al., 2012; White et al., 2021; White, Alcock, et al., 2013). Previous research found that spending time near the ocean reduces stress (Hooyberg, Michels, et al., 2023; Triguero-Mas et al., 2017; Vert et al., 2020), promotes physical activity (Elliott et al., 2015; White et al., 2015; White, Wheeler, et al., 2014), and provides a setting to meet with family and friends (Ashbullby et al., 2013; Siân de Bell et al., 2017; van den Bogerd et al., 2021). It is now clear that residing in closer proximity to the coast and visiting the coast more often effectuates these benefits, similarly as what has been evidenced for inland blue spaces and green spaces (Elliott et al., 2015, 2023; van den Bogerd et al., 2021; White et al., 2020). However, it is still unknown to which extent the characteristics of the coastal visit and visitor modify the health outcomes.

Studies from across the globe provided the initial evidence for the beneficial effects of the coast by revealing that residing in closer proximity to the coast is associated with a better self-reported general health (e.g., in Belgium (Hooyberg et al., 2020), Canada (Crouse et al., 2018), China (Garrett, White, et al., 2019), Ireland (Brereton et al., 2008; Dempsey et al., 2018), Japan (Peng et al., 2016b), Spain (Ballesteros-Olza et al., 2020), and the United Kingdom (Alcock et al., 2015; Wheeler et al., 2012, 2015; White, Alcock, et al., 2013)). Several reviews and conceptual frameworks hypothesized that this pattern occurs because people who live nearer the coast tend to visit it more often (Georgiou et al., 2021; Hartig et al., 2014; Smith et al., 2021; White et al., 2020) (Figure 19a). Indeed, cross-country analyses have confirmed that living nearer the coast is associated with a higher coastal visit frequency (Elliott et al., 2020; Geiger et al., 2023) and that a higher coastal visit frequency is associated with a better self-reported general health (Geiger et al., 2023; White et al., 2021). It also seemed that these pathways are moderated by the demographic and socio-economic characteristics and health of the individual (Georgiou et al., 2021; Hartig et al., 2014; Smith et al., 2021; White et al., 2020). For example, Boyd et al. (2018) clearly illustrated for England that "infrequent users [of coastal environments] were more likely to be female, older, in poor health, of lower socioeconomic status, of ethnic minority status, live in relatively deprived areas with less neighborhood greenspace and be further from the coast". However, examples from outside England are now required to strengthen our understanding about how individual characteristics moderate the coastal visit frequency and experienced health effects.

Next to the visit frequency, the visit characteristics may be an equally important mechanism by which residential proximity benefits general health. Coastal visitors perform many different leisure activities at the coast (Elliott et al., 2018), and each activity may result in distinct emotional, cognitive, and physical experiences that contribute to overall health (Fancourt et al., 2021). Depending on the individual's socio-demography and health, different activities may be performed and different health effects may be experienced (Elliott et al., 2018). Unfortunately, no study seems to have yet investigated who performs what kinds of recreational activities at the coast, and whether these different activities at the coast result in different experiences and health effects (Figure 19a).

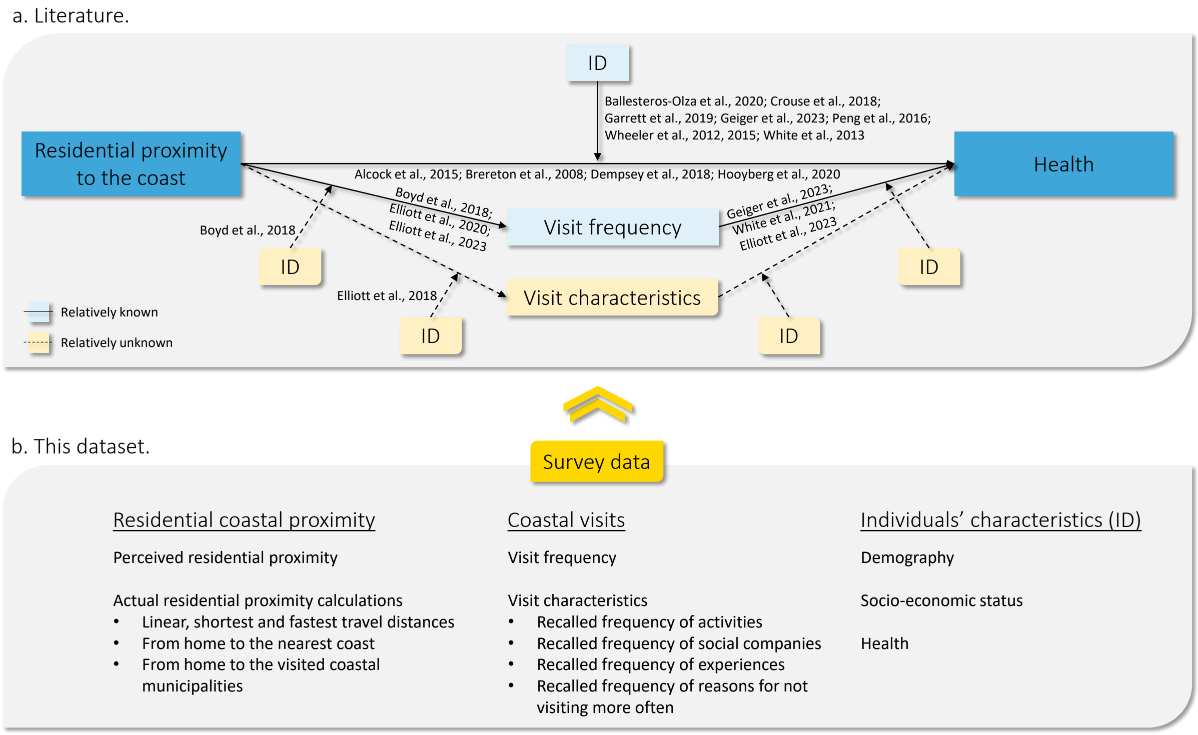


Figure 19: Overview of what this dataset contributes to the current literature. Panel a shows a conceptual diagram of the mediating roles of visit frequency and visit characteristics and the moderating role of individual traits (ID) in explaining the benefits of residential coastal proximity for health. A distinction is made between what is known from the literature and what this data provides to complement existing knowledge. Panel b shows what this dataset contains.

1.1. Knowledge gap

There is a lack of high-quality scientific data that links individual characteristics such as residential proximity, demography, socio-economic status, and health to the coastal visit frequency and visit characteristics and the resulting emotional, cognitive, and physical experiences. Coastal nations' tourism agencies usually do survey the activities, reasons, and experiences with the coastal amenities alongside the demographic features of their coastal visitors. However, in many cases, crucial variables such as residential coastal proximity, socio-economic status, and what people experienced emotionally and cognitively are neglected, because collecting the data often merely must serve the optimization of blue tourism. England seems to be an exception, because there the Monitor of Engagement with the Natural Environment (MENE) survey queries where people go, what they do, and what they experienced at the coast, alongside age, gender, deprivation indexes, and other characteristics of the individuals. This data has proven to be very effective for science, because it has led to significant advancements in the current knowledge about coastal recreation and health relationships (Boyd et al., 2018; Elliott et al., 2015, 2018; White, Pahl, et al., 2013, 2017).

1.2. Purpose of this dataset

The aim of this research was to develop a dataset that allows to perform confirmatory and exploratory investigations on the relationships between residential proximity to the coast and the resulting mental and physical experiences via the mediating effects of the visit frequency and characteristics, and the moderating role of the individuals' socio-demography and health (Figure 19b). Therefore, a survey was distributed among Flemish-speaking Belgian inhabitants and their visits to the Belgian coast (i.e., not international coastal tourism). We deliberately focused on a local scale to be able to reveal a diversity of relationships and patterns within the locally-specific cultural landscape. The data contains the visit frequency, visited municipal seaside resorts, performed activities, gained experiences, and applicable reasons for not visiting the coast more often alongside the geographic (i.e., postal codes), demographic, socio-economic, and health profiles of the respondents. We supplemented this data with the objective linear distances, shortest, and fastest driving distances from the centers of the home municipalities to the nearest and actually visited municipal seaside resorts, similarly as in previous research (Hooyberg et al., 2020; Wheeler et al., 2012). The dataset holds complete responses from 1939 respondents, of whom 1304 had visited the Belgian coast in the preceding year (67.25%), 627 had not visited the coast in the preceding year but did before (32.34%), and eight respondents had never visited the Belgian coast (0.41%). For the users' convenience, each variable in the raw and processed data is given a detailed description in a codebook that is shared along with the data (folder '3. Processing').

The dataset may be of interest for researchers aiming to disentangle relationships between the ocean and human health and for stakeholders of blue tourism. More specifically, the data allows to unravel the social structuring of recreational activities to the coast, which can be analyzed via multivariate modelling or ordination techniques. Alternatively, the data can also contribute to a number of ongoing investigations in the literature, and we propose thematic research questions that may be addressed with the data: about 'coastal epidemiology and accessibility', 'health and psycho-physical experiences', 'social relations', and 'issues of time, season, and weather' (Table 9). Four fields of application for the data are identified: to increase our understanding of the coastal recreation phenomenon; to help to address the needs, challenges, and opportunities in the blue tourism sector; to evaluate whether and how the coast can be used for new cost-effective health-care practices (e.g., coastal visits on prescription); and to help spatial planners to design the coast up to the needs of the residents and visitors. This publication provides univariate descriptions of the data, which can assist in shedding light on the variation present in the data and the quality of the data. By making this dataset publicly available and in accordance with FAIR principles, it also calls to researchers and tourism agencies to standardize coastal tourism questionnaires and make existing and newly acquired data openly available.

Table 9: A non-exhaustive list of thematic research questions that can be addressed with the proposed dataset. The themes may overlap with each other.

Potential uses of the proposed dataset
1) Unravelling the social structuring of coastal visits • Which demographic, socio-economic and health profiles are associated with which visit frequency and recreational activities, social company, and experiences at the coast and with which reasons for not visiting the coast more often? 2) Contributing to ongoing investigations in the literature • Coastal epidemiology and accessibility i. Is living nearer the coast associated with a better self-reported general and mental health? ii. Is living nearer the coast associated with more physical activity and social support? iii. Is living nearer the coast associated with a higher coastal visit frequency? iv. How well does the perceived residential proximity match with the actual residential proximity? v. What are reasons for not visiting the coast more often? vi. What municipal seaside resorts are visited for performing which coastal activities? vii. Do coastal residents perform different kinds of activities and visit different seaside resorts than tourists from inland? viii. How do these relations differ for people with a poorer mental and physical health or poorer socio-economic status? • Health – Psycho-physical experiences i. What experiences are gained from visiting the coast and do these experiences support attention restoration theory and psycho-evolutionary theory? ii. How do the experiences at the coast link with the visit frequency and the performed activities? iii. Do citizens who have a poorer health or chronic illnesses visit the coast more/less often and perform different activities compared to citizens who are healthy, and (how) do their experiences differ? iv. Can visiting the coast minimize health disparities? • Social relations i. How does the household composition and level of social support relate to the visit frequency, the activities performed, and the social company during the coastal visits? ii. How does the social company associate with particular experiences during the visit? iii. How does summer crowding and off-season calmness affect visitors' experiences, and reasons for not visiting the coast more often? • Season – Weather – Time i. How are a person's occupational status and time availability linked to the coastal visit frequency, in which season the coast is visited, and the reasons for not visiting the coast more often? ii. How do the season in which the coast is visited and the different weather phenomena (e.g., wind, clouds, precipitation) associated with the experiences and for who is the season/weather a reason for not visiting the coast more often? iii. Does the visit frequency and residential proximity during childhood relate to the (nostalgic) experiences at the coast now?

2. Methods

2.1. Survey

The dataset contains the responses to an online survey about the performed recreational visits to the Belgian coast and the demographic, socio-economic, and health background of the respondents. The survey was distributed among a panel of 30.000 to 35.000 Flemish-speaking members from the five provinces in Flanders that had subscribed to participate in societally relevant research (Bpact, Leuven, Belgium). It was distributed from January 2nd to January 17th 2023 to meet the intended number of 1640 complete responses. Sampling happened via quota sampling based on data on age (<34y, 35-49y, 50-64y, 50-64y and >65y), sex, province, and educational attainment (categories: low, middle, high) previously gathered by the panel provider. Sampling happened during multiple waves while considering propensity scores per quota. Oversampling of quotas was allowed, and no exclusion criteria were set. In total, 2574 panelists responded to the survey, of whom 1939 provided a complete and reliable response (see section 4. Technical Validation). The respondents received points from the panel provider (quantity unknown for the researchers) for the time spent on the survey, and these points add up to an appropriate monetary compensation. The survey was anonymous and consent for voluntary participation was acquired via panel subscription. The research was conducted according to the ethical rules presented in the General Ethical Protocol of the Faculty of Psychology and Educational Sciences of Ghent University. The survey was administered in Dutch via the online Bpact user interface and Qualtrics software (Qualtrics, 2022). The survey itself can be found within the data (Hooyberg, Roose, et al., 2023) in the folder '/1. Survey' and the acquired responses in folder '/2. Raw data/a. Survey responses/'.

Asking about respondents' socio-demographic background and health could lead to social desirability bias. To be able to assess potential measurement error, we asked at the end of the survey how comfortable the respondents were with answering each section of the survey (i.e., about coastal visits, demography, employment situation and income, and health) using a five-item multiple choice with answers 'very discomfortable', 'discomfortable', 'neutral', 'comfortable', and 'very comfortable' (Billiet & Waege, 2009).

2.1.1. Coastal visits

The questions about the coastal visits in the survey were designed to optimally capture the diversity of visit frequencies and characteristics. Furthermore, the questions meant to capture the respondents' general perceptions and trends about many of their past coastal visits across seasons and years, rather than detailed information about only a couple of their visits. These general perceptions and trends were deemed to be more indicative for summarizing a respondent's coastal visit behavior and for distinguishing behaviors across socio-demographic groups. Coastal visits were operationalized as days at which the person was at the Belgian coast in a recreational context and saw the sea. Depending on whether the respondents' visited the Belgian coast in the previous year or before that, the reference period differed and additional questions about the frequency and locations of the performed visits were asked (Table 10). All respondents were asked to report how frequent 32 activities were (or would be) performed, how frequent the person was (or would be) accompanied by 7 types of social company, how frequent 27 experiences were (or would be) felt, and how frequent 18 reasons for not visiting the coast more often applied (or would apply; Table 10). Response categories for these questions were ‘never’, ‘seldom’, ‘sometimes’, ‘often’, and ‘always’. The items and response categories of the activities, types of social company, experiences, and reasons for not visiting the coast more often were chosen based on the local culture, the potential outcomes and mechanisms described in the nature and health literature (Hartig et al., 2014; Stevenson et al., 2018; Ulrich et al., 1991; White et al., 2020), previous studies about the experiences along the Belgian coast (Hooyberg, Michels, et al., 2022; Severin et al., 2022), and the following previous surveys: the ‘Monitor of Engagement with the Natural Environment’ survey being administered nationally in England (MENE; Elliott et al., 2018; Natural England, 2019), the ‘Cultural participation in Flanders’ surveys being administered yearly in Flanders (from 1996 as the ‘SCV-survey’; Carton et al., 2017; Lievens et al., 2006; Roose et al., 2014); and since 2019 as part of Flanders’ ‘SV-survey’), and the surveys administered to day visitors and stayers in coastal accommodations by the local tourism agency aimed at informing policy (Westtoer et al., 2022; Westtoer & De Kust, 2018). Thus, we did not blindly copy item sets that were available in the literature, but rather invented our own based on our perspectives on the current knowledge. The respondents who visited the coast in the previous year also had to report for each of the four seasons within that year how many days the person was at the coast during a day coastal visit or during a multi-day visit with overnight stay in an accommodation. They also had to report which of the 14 municipal seaside resorts were visited. The respondents who had not visited the coast in the previous year but did before had to additionally report the frequency of coastal visits in that period, and which of the 14 municipal seaside resorts were then visited. Figure 20 displays the variation in the responses with regard to the coastal visits.

Table 10: Overview of the questions about the visits to the Belgian coast that were asked to the respondents who visited the Belgian coast in the previous year, to those who did not visit the Belgian coast in the previous year but visited the Belgian coast before that, and to those who never visited the Belgian coast.

Categorization questions	Have you visited the Belgian coast in the previous year?		
	Answer: Yes	Answer: No	
		Have you ever visited the Belgian coast?	
		Answer: Yes	Answer: No
Reference	Referring to the previous year (Jan. 1st 2022 to Dec. 31st 2022)	Referring to the last time(s) that the individual visited the Belgian coast	Referring to a hypothetical scenario in which the individual would visit the coast
Question topics	14 Municipal seaside resorts	14 Municipal seaside resorts	/
	Days and stays per season in the previous year	Year of the last visit	/
		Frequency of coastal visits in the year preceding the last visit	
	32 Activities	32 Activities	32 Activities
	7 Types of social company	7 Types of social company	7 Types of social company
	27 Experiences	27 Experiences	27 Experiences
	18 Reasons for not visiting the coast more often	18 Reasons for not visiting the coast more often	18 Reasons for not visiting the coast more often

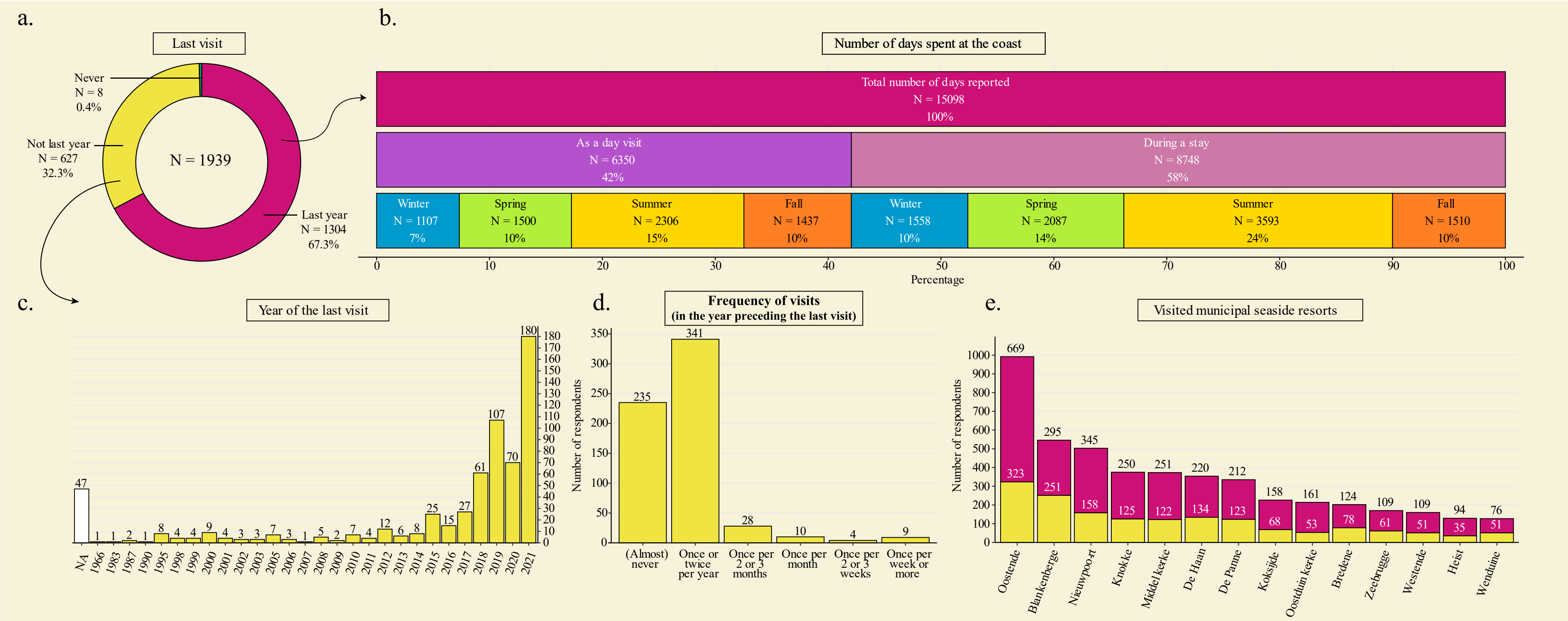
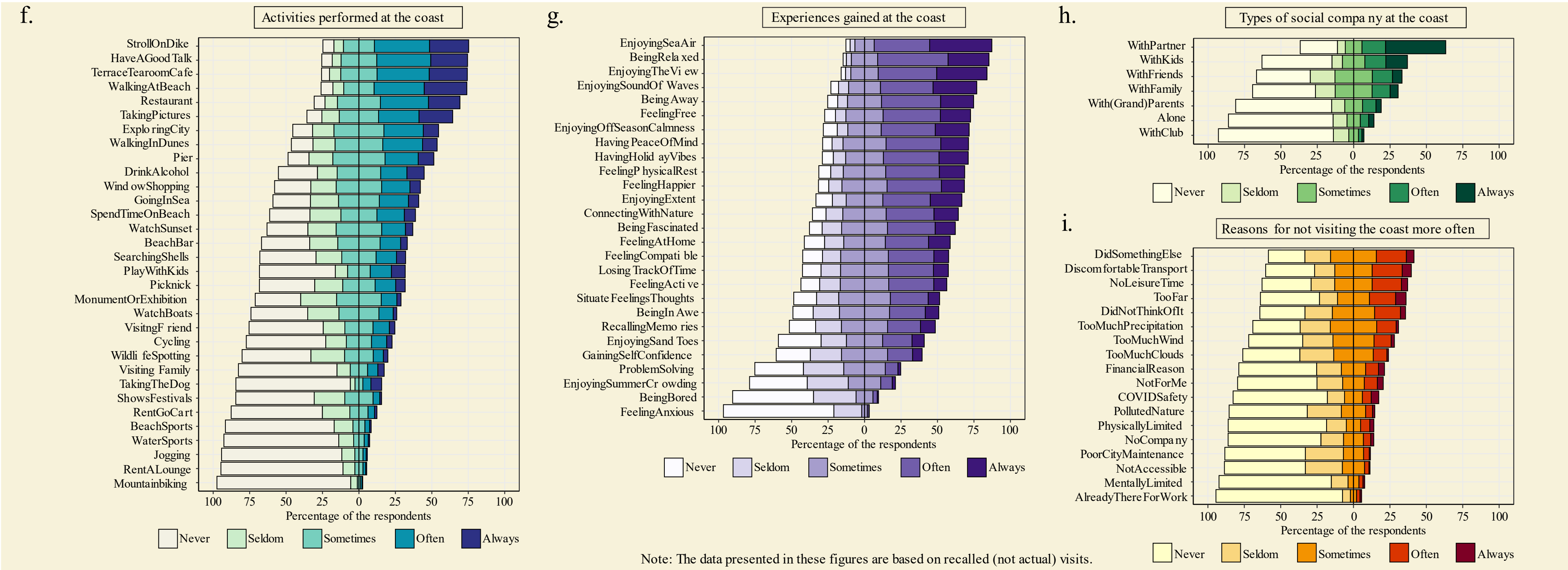


Figure 20: Descriptive graphs of the queried coastal visit frequency and coastal visit characteristics. Panels a to d show the acquired information about the visit frequency, panels e to i about the visit characteristics.



Note: The data presented in these figures are based on recalled (not actual) visits.

(Figure 20 continued)

Note that the Belgian coast consists of 10 administrative municipalities, but the names that Belgian citizens commonly give to the 14 municipal seaside resorts often differ from the administrative boundaries (Table 11, Figure 21).

Table 11: The names of the municipal seaside resorts as queried in the survey and the administrative sub-municipalities to which they respectively refer to.

Name of the municipal seaside resort as queried in the survey	Administrative sub-municipality(/-ies) belonging to the municipal seaside resort	Administrative municipality to which the sub-municipality(/-ies) belong(s) to
Blankenberge	Blankenberge	Blankenberge
Bredene	Bredene	Bredene
De Haan	Klemskerke + Vlissegem	De Haan
De Panne	De Panne	De Panne
Heist	Heist	Knokke-Heist
Knokke	Knokke	Knokke-Heist
Koksijde	Koksijde	Koksijde
Middelkerke	Middelkerke	Middelkerke
Nieuwpoort	Nieuwpoort	Nieuwpoort
Oostduinkerke	Oostduinkerke	Koksijde
Oostende	Oostende	Oostende
Wenduine	Wenduine	Wenduine
Westende	Westende + Lombardsijde	Middelkerke
Zeebrugge	Lissewege	Brugge

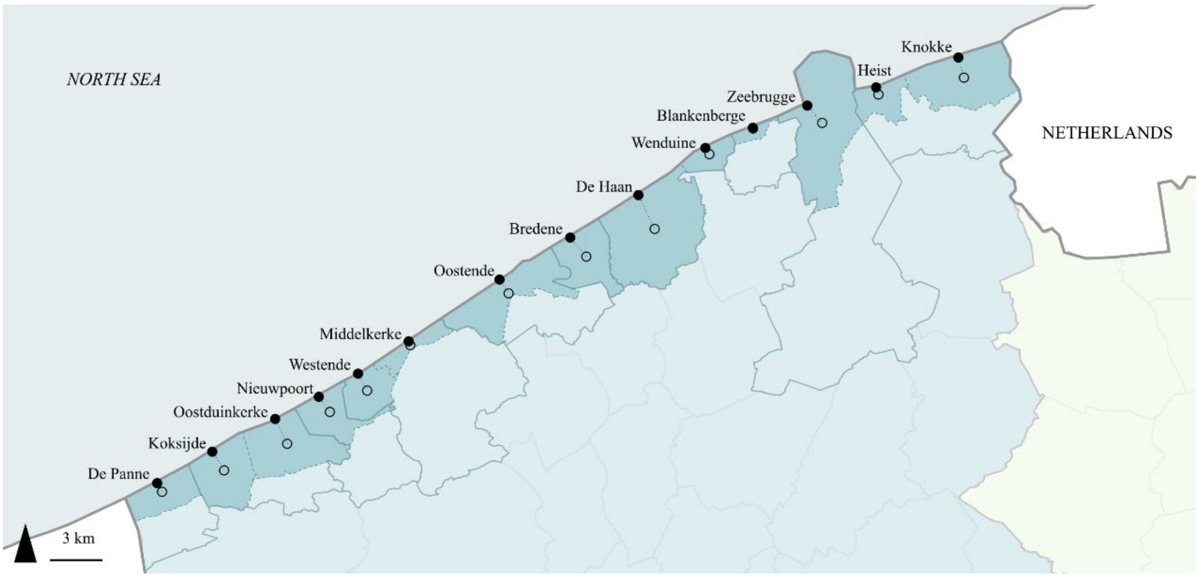


Figure 21: Map of the Belgian coast with municipal seaside resorts queried in the survey. Municipality borders are delineated by a solid line, the borders of sub-municipalities to which the seaside resorts belong by a dashed line. Open black circles represent the centroids of the polygons of the municipal seaside resorts, solid black circles the modelled destinations.

2.1.2. Demographic background

The section in the survey about the demographic background aimed to capture the diversity in who the respondents are and who they are surrounded by in everyday life. The queried traits of the respondents were the following: year of birth, gender, the postal code of the primary residence, four optional postal codes of secondary residence locations, whether the respondent had a secondary residence at the coast that is sometimes visited for leisure, the perceived residential distance to the nearest coastline, the number and types of co-inhabitants, the number of people on which the respondent can count on when faced with serious problems (this invented proxy for social support is a simplified version of a previously-published single-item questionnaire for social support (Slavin et al., 2020), and hints to the same constructs as a multi-item social support questionnaire; Sarason et al., 1983), whether and where the person grew up in Belgium, and how often the coast was visited during childhood. The user can link these data to the frequency and characteristics of the coastal visits to evaluate the influence of geography, the social context, and mechanisms of nostalgia – an emotion that has proven to be crucial when investigating coastal visits and experiences (Jarratt & Gammon, 2016; Severin et al., 2022). Figure 22 panels a, b, c, f, j, and k visualize the variation in these demographic parameters. Some respondents' postal codes (1000 and 1090) were in the Brussels-Capital Region (N = 2), where was not meant to be sampled via the panel, but we kept these respondents in the data for completeness.

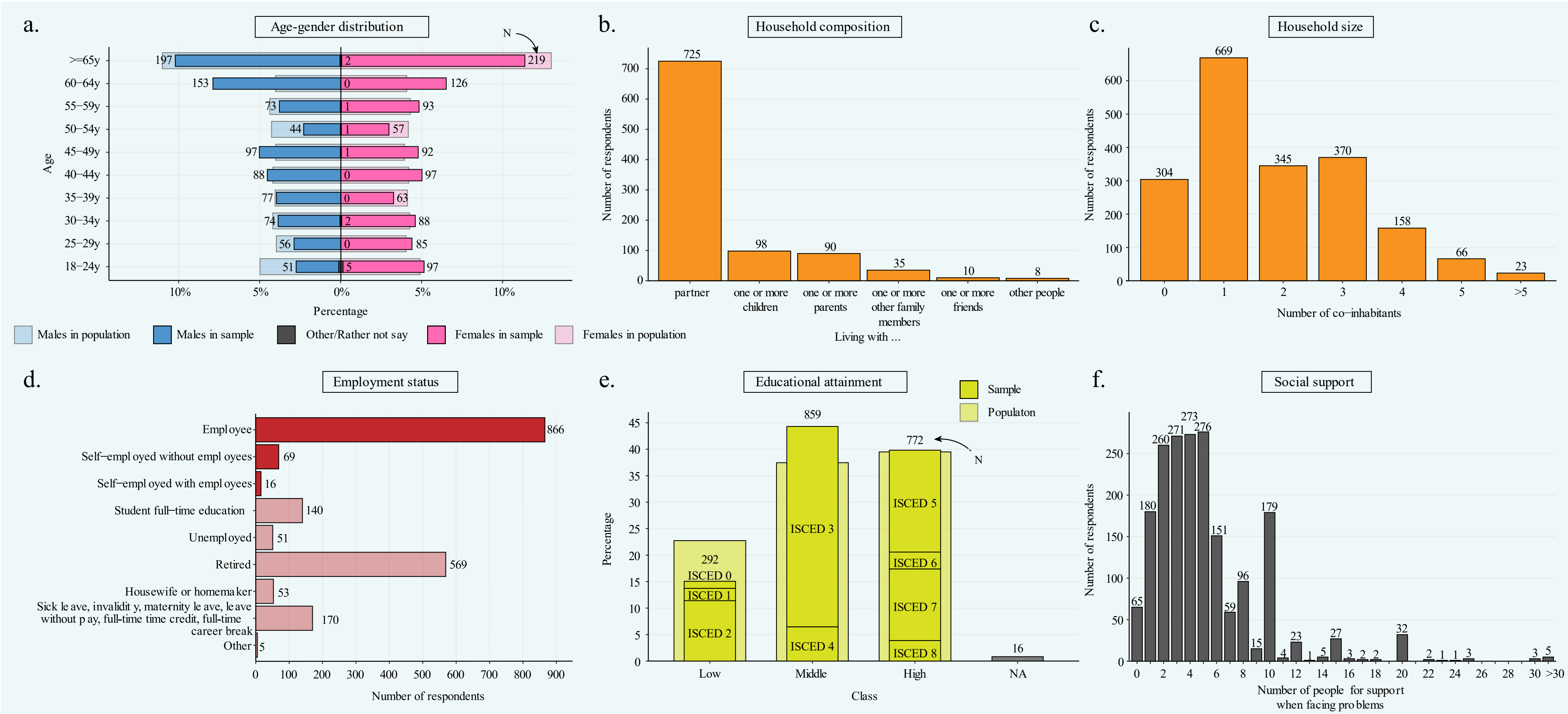
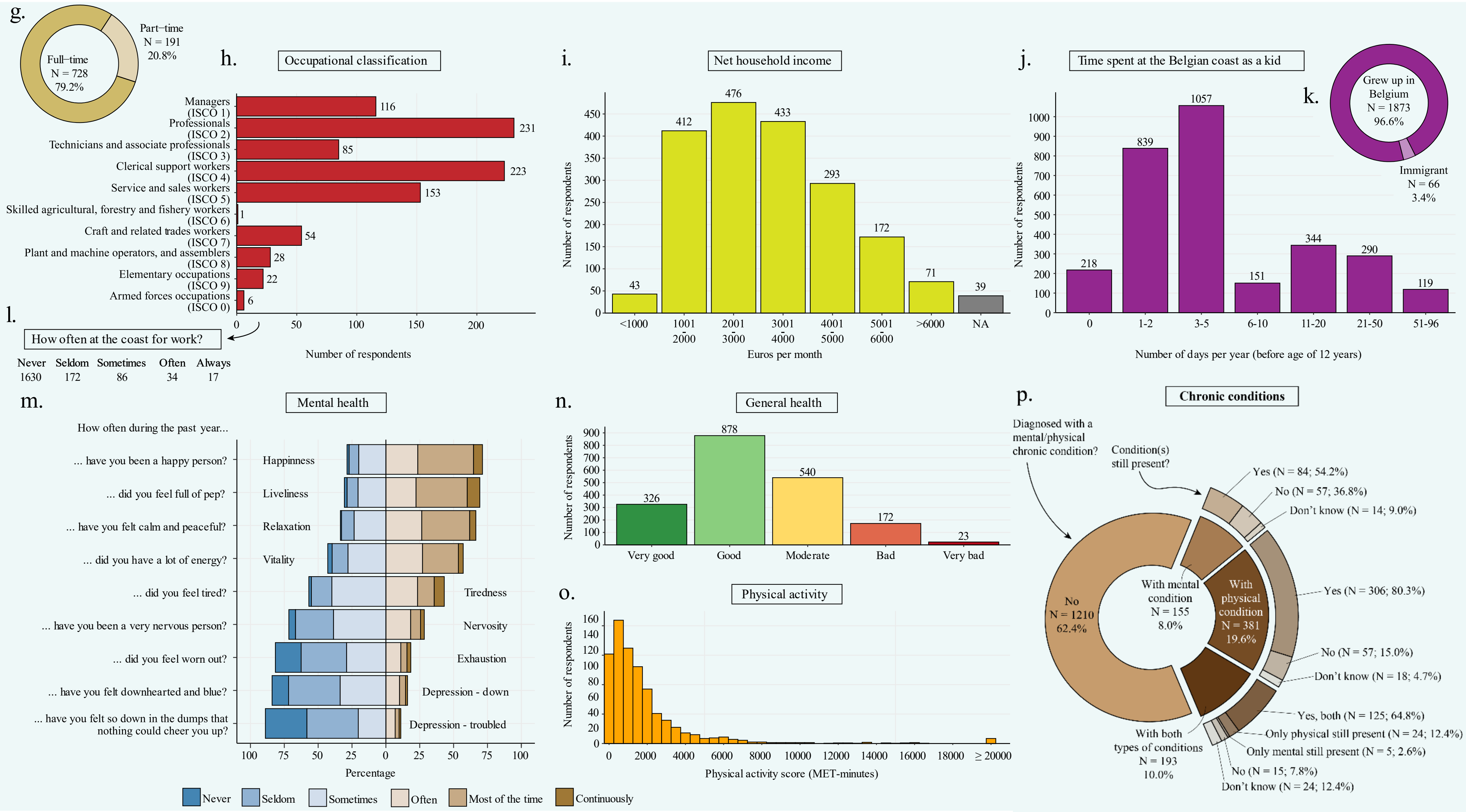


Figure 22: Descriptive graphs of the demography, socio-economic status, and health of the respondents. Panels a, b, c, f, j, and k show the demographic and social context of the respondents, panels d, e, g, h, i, and l show the socio-economic context, and panels m, n, o, and p their health and physical activity.



(Figure 22 continued)

2.1.3. Socio-economic status

The survey included different proxies for the respondents' socio-economic status. Firstly, the educational attainment was queried using the descriptions of the nine main categories in the International Standard Classification of Education (ISCED 0 to 8). There was also an 'other' category where respondents could specify their educational degree in case of uncertainty, but this resulted in some unclear responses that were identified as 'NA'. Secondly, the employment situation distinguished the active (i.e., employee, self-employed with and without employees, student full-time education) from non-active (i.e., unemployed, retired, housewife or homemaker, out due to sickness or other circumstances) population using a multiple-choice question with one possible answer. There was also an 'other' category. The employees and self-employed respondents were also asked about their employment time (i.e., working full-time or part-time) and their occupational classification using the first-order and second-order classifications of the International Standard Classification of Occupations (ISCO). Lastly, all respondents were asked about their net household income using increments of thousands (i.e., <1000 euros/month, 1001-2000 euros/month, …, >6001 euros/month). The survey also queried how often the respondent's occupation involved being at a coastal or marine environment to evaluate the potential of constrained restoration (Hartig et al., 2007; Macaulay et al., 2022; von Lindern et al., 2017; Von Lindern et al., 2013). Figure 22 panels d, e, g, h, I, and i visualize the variation in the socio-economic responses.

2.1.4. Health

Information about the health of the respondents was gathered for three reasons. First, it could help evaluate whether coastal visit behaviors are moderated by a person's mental and physical health, for example in cases of limited mobility or depressive symptoms and social isolation. Second, it could help identify whether particular coastal visit behaviors, such as visiting the coast more often or performing particular coastal activities, are associated with a better or worse health as an outcome. Thirdly, it could provide further support for the relationship between living nearer the coast and self-reported general health or other proxy for health (Hooyberg et al., 2020). The questions related to the health of the respondents included the self-reported general health (first item from the short-form health survey, SF1), aspects of mental health (mental health part of the short-form health survey, SF36MH), including items referring to arousal/vitality (liveliness, vitality, exhaustion, tiredness) and to the valence/emotionality (nervosity, depression – feeling troubled, depression – feeling down, happiness), and having been diagnosed with a mental or physical chronic condition and whether this condition is still present. Also questioned were the time spent doing light, moderate, and intense physical activity in the past month (international physical activity questionnaire short form; IPAQ-SF) (Lee et al., 2011), Figure 22 panels m-p visualize the variation in the health of the respondents.

2.1.5. Nature connectedness

The survey was closed with a one-item question about the respondents' nature connectedness, stating "Do you rather agree or disagree with the following sentence? Like a tree can be part of a forest, I feel embedded within the broader natural world". Answers categories were 'totally agree', 'agree', 'neutral', 'disagree', 'totally disagree'. This question is one item from the connectedness to nature scale that has shown to be particularly indicative of nature connectedness based on item response theory (Pasca et al., 2017).

2.2. Processing steps

The processing steps with regard to the survey data can be found in Table 12.

Table 12: Listed questions of the survey and the type of answers and processing steps. Besides the mentioned processing steps, every variable was also translated from Dutch to English.

[1] Some respondents stated to not have visited the coast in 2022 but indicated the year of their last visit was 2022 (N = 34) or 2023 (N = 3). These values were set to 'not available' (NA).

[2] Some postal codes did not match with an existing administrative (sub-)municipality and were set to 'not available' (NA). Space characters were neglected, and postal codes with more or less than four digits or that contained non-numeric characters were set to 'not available' (NA).

Category	Question topic	Answer type	Processing steps
Coastal visits	Visited coast in the previous year	Yes/No	Used to distinguish three types of visitors (visited last year, visited not last year but before, never visited)
	Ever visited the coast	Yes/No	
	Visited municipal seaside resorts	Multiple choice	For each seaside resort dichotomized into Yes/No
	Day visits to the coast in winter, spring, summer, and fall in the previous year	Numerical input	Number of days at the coast summed per season, per day visits, and per longer stays; Number of days topped off at theoretical maximum quantities
	Days at the coast during longer stays in winter, spring, summer, and fall in the previous year	Numerical input	
	Year of the last visit	Numerical input	Years > 2021 set to NA[1]
	Frequency of coastal visits in the year preceding the last visit	Single choice	/
	Frequency of performed activities	Single choice	/
	Frequency of types of social company	Single choice	/
	Frequency of experiences	Single choice	/
	Frequency of reasons for not visiting the coast more often	Single choice	/
Demography	Birth year	Numerical input	Used to derive the age

	Gender	Single choice	/
	Postal code(s) of residence (one primary and four optional secondary postal codes)	Numerical input	Cleaned[2]
	Perceived residential proximity to the coast	Single choice	/
	Grew up in Belgium	Yes/No	/
	Postal code of residence at age 5-15 years (one primary and four optional secondary postal codes)	Numerical input	Cleaned[2]
	Perceived average number of days per year at the coast at age < 12 years	Numerical input	Topped off at 365
	Number of co-inhabitants	Numerical input	/
	Types of co-inhabitants	Multiple choice	Corrected choice 'other'; Dichotomized
	Social support	Numerical input	/
	Having a holiday residence at the Belgian coast	Yes/No	/
Socio-economic status	Educational attainment (ISCED)	Categorical	Assigned ISCED codes; Corrected choice 'other'
	Employment situation	Single choice	Corrected choice 'other'; Dichotomized
	Employment full/half time	Single choice	/
	Occupation (ISCO)	Single choice	Assigned ISCO codes; Corrected choice 'other'
	Frequency of being at the coast for work	Single choice	/
	Net household income	Single choice	/
Health	Number of minutes of light, moderate, and high intensity physical activity per week (IPAQ-SF)	Numerical input	Each topped off at theoretical maximum quantities, then multiplied by METs and summed
	Self-reported general health (SF1)	Single choice	/
	Diagnosed with a chronic mental condition	Yes (specify)/No	Specifications categorized
	Chronic mental condition still present	Yes/No	/

	Diagnosed with a chronic physical condition	Yes (specify)/No	Specifications categorized
	Chronic physical condition still present	Yes/No	/
	Mental health (Short Form 36 mental health)	Single choice	Average scores calculated for all items, and items of vitality and emotional health
Closing questions	Comfort of responding to questions about coastal visits, demography, employment situation and income, and health	Single choice	/
	Connectedness to nature	Single choice	/

2.3. Additional calculations

2.3.1. Weights

The quota sampling inevitably caused the representativeness of the sample for the population to be imperfect. To clarify these sampling errors and correct for them to a possible degree, post-stratification weights were calculated for different strata based on the combinations of age (18-29y, 30-39y, 40-49y, 50-59y, 60-64y, >=65y, total), sex (male, female, total), educational attainment (low, middle, high, total), and province (West Flanders, East Flanders, Antwerp, Limburg, Flemish Brabant, total). For each stratum, the weight was calculated as the frequency of individuals that belong to the stratum in the population divided by the frequency of individuals that belong to the stratum in the sample. Population statistics were retrieved from Statbel (2023). The number of strata were reduced to retain the specificity of the strata while limiting the number of excessively high or low weights due to exceptionally under- or oversampled strata, respectively. More specifically, consecutive age categories that were either both under- or both over-represented by the sample were pooled together (Figure 22 panel a), so that the deviations from representativeness did not cancel out during the pooling. Since the population data contained sex data, and not gender data as in the survey, we had to considered the gender categories ‘Male’ and ‘Female’ to be matching the sexes ‘Male’ and ‘Female’ from the population. This gender-sex linkage and the different meanings of these concepts may have resulted in misrepresentative weights. Educational attainment was pooled into ‘Low’, ‘Middle’, and ‘High’, because the quota sampling also adopted these categories and this considerably decreased the number of excessively high weights. The Province categories were not adjusted to retain geographical specificity for each weight. If information for these four parameters were incomplete for an individual (e.g., NA for Educational attainment), those parameters were disregarded and the weight was calculated based on the parameters for which information was available. There were 504 strata with different combinations of age, gender-sex, educational attainment, and province categories. The weights were trimmed at 0.2 and 5. The population statistics retrieved from Statbel (2023) can be found within the data (Hooyberg, Roose, et al., 2023) in the folder '/2. Raw data/b. Population socio-demographics/'. The weights table with pooled ISCED and age categories as described above is stored within the data (Hooyberg, Roose, et al., 2023) on location '/3. Processing/R workspace/Weights.ISCEDLMH.Age.csv'. All weights were appended to the final processed survey data.

2.3.2. Residential proximity to the coast

Residential proximity to the coast was operationalized in different ways depending on the type of residence (primary and secondary; in 2022 and as a child), the destination (nearest coast vs. visited seaside resorts), and the route between the two (linear, shortest and fastest driving route; Figure 23). Firstly, the distances were calculated from all residential primary and secondary postal codes in 2022 and as a child to the nearest coast. Secondly, the distances were calculated from the residential primary and secondary postal codes in 2022 to the actually visited seaside resorts in that year. As such, the user of this dataset can choose the proxy that is best suited for quantifying the residential proximity to the coast. For each distance, the residential municipality centroids were used as starting point. The distances corresponding with the linear and shortest and fastest driving routes were derived in kilometers, and for the shortest and fastest driving routes also in the number of seconds travel time. The destination points of the visited seaside resorts were the points along the shorelines that were closest to the centroids of the municipal seaside resorts (Figure 21). The routes and accompanying distances were calculated with GIS-methods: QuantumGIS 3.2.2 was used to generate a map with the OpenStreetMap road network (OpenStreetMap contributors, 2018) and Eurostat coastline data (Nomenclature of Territorial Units for Statistics (NUTS), 2013) and the ArcGIS Pro 2.2.0 Network Analyst extension was used to generate the routes and calculate the distances. Next to these objective measures of residential proximity, the perceived residential proximity (in kilometers) to the nearest coast (in kilometers) was also queried in the survey. The raw distances calculated via GIS can be found within the data (Hooyberg, Roose, et al., 2023) in the folder '/2. Raw data/c. Residential distances to the coast/'. The distances to the nearest coast were appended to the survey data with R (R Core Team, 2018), which is stored at '/4. Processed data/' in the files 'Hooyberg_Survey_Processed.csv' and 'Hooyberg_Survey_Processed.txt'. The distances to the destinations were stored in a separate dataset due to its long format in the folder '/4. Processed data/' in the files 'Hooyberg_Distances_Processed.csv' and 'Hooyberg_Distances_Processed.txt'. The dataset also holds a merged dataset with all survey data and distances under the folder '/4. Processed data'/ in files 'Hooyberg_Survey_Distances_Processed.csv' and 'Hooyberg_Survey_Distances_Processed.txt'.

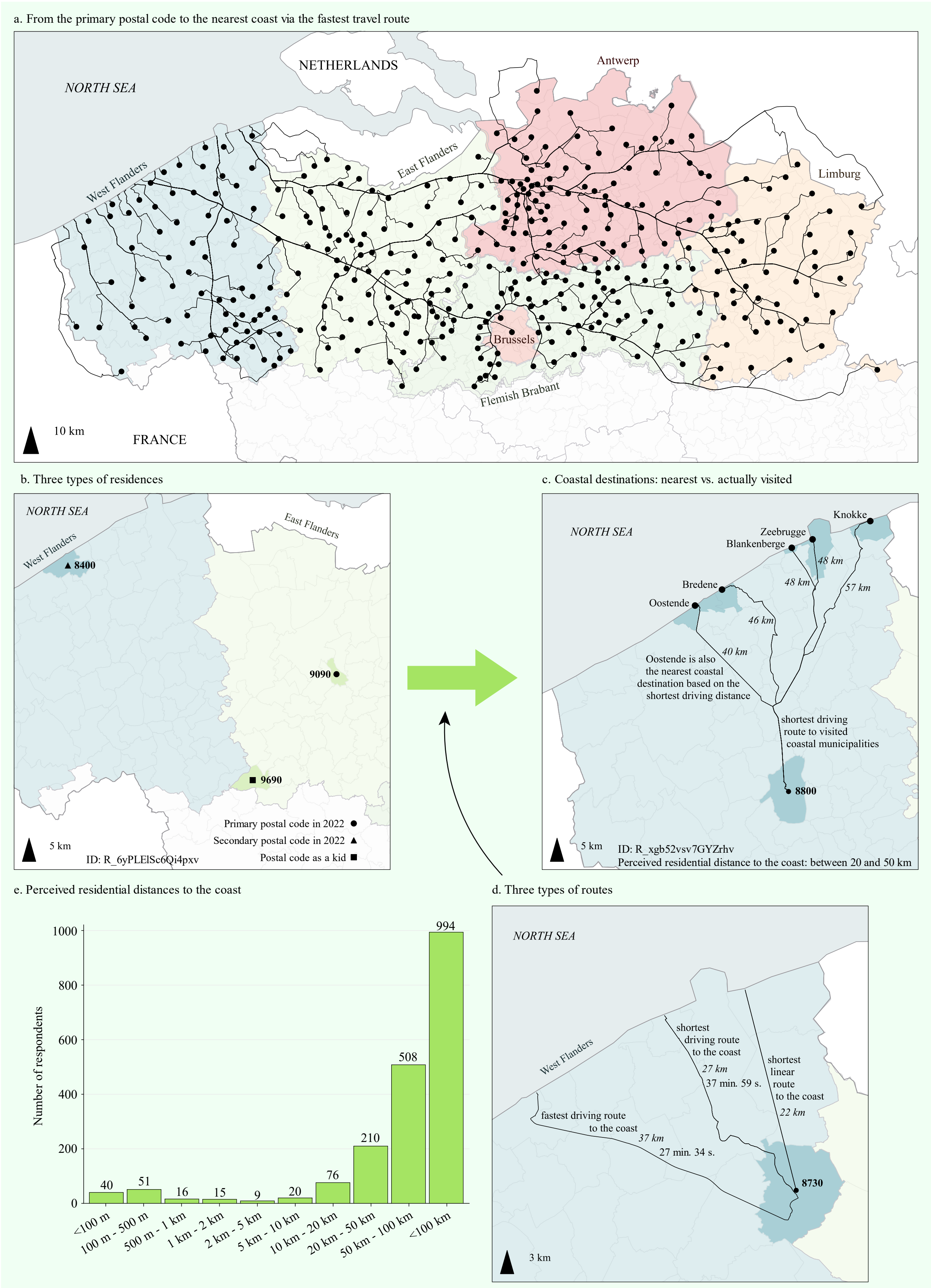

a. From the primary postal code to the nearest coast via the fastest travel route
NORTH SEA
NETHERLANDS
Antwerp
East Flanders
West Flanders
Limburg
Brussels
Flemish Brabant
10 km
FRANCE
b. Three types of residences
NORTH SEA
West Flanders
East Flanders
8400
9090
9690
5 km
ID: R_6yPLElSc6Qi4pxv
Primary postal code in 2022
Secondary postal code in 2022
Postal code as a kid
c. Coastal destinations: nearest vs. actually visited
NORTH SEA
Knokke
Zeebrugge
Blankenberge
Bredene
Oostende
48 km
48 km
57 km
46 km
40 km
Oostende is also the nearest coastal destination based on the shortest driving distance
shortest driving route to visited coastal municipalities
8800
5 km
ID: R_xgb52vsv7GYZrhv
Perceived residential distance to the coast: between 20 and 50 km
e. Perceived residential distances to the coast
Number of respondents
1000
800
600
400
200
0
40
51
16
15
9
20
76
210
508
994
<100 m
100 m - 500 m
500 m - 1 km
1 km - 2 km
2 km - 5 km
5 km - 10 km
10 km - 20 km
20 km - 50 km
50 km - 100 km
<100 km
d. Three types of routes
NORTH SEA
West Flanders
shortest driving route to the coast
27 km
37 min. 59 s.
shortest linear route to the coast
22 km
fastest driving route to the coast
37 km
27 min. 34 s.
8730
3 km

Figure 23: Visualization of the proxies for residential proximity to the coast. Panel a displays the sampled municipalities and the fastest driving routes to the coast. Panel b shows an example of three types of residences of a respondent. Panel c illustrates that the distance can be calculated to the nearest coast and to the actually visited seaside resorts from the primary postal code in 2022 from a respondent. Panel d displays an example of the different types of routes and associated distances and travel times to the nearest coast. Panel e shows the summary of the respondents' perceived residential distance to the nearest coast.

3. Data Records

To provide the reader with maximal transparency about the questioning of the items in the survey and the processing steps implemented for the final datasets, the zipped data contains four folders with the survey itself, the raw data, the processing process, the processed data, and the figures. All data can be found within the data (Hooyberg, Roose, et al., 2023). The zipped file is 161 megabytes in size and the unzipped file 372 megabytes.

3.1. Folder '1. Survey'

The first folder provides the survey in different formats and languages. The survey was administered in Dutch using the Qualtrics survey administration software, and translations were added in Qualtrics later for publication.

- The file 'Hooyberg_SurveyCoastalVisits_NL.docx' is the exported human-readable format of the survey with all the rules and flows of the survey in the original language Dutch.
- The file 'Hooyberg_SurveyCoastalVisits_ENG.docx' is the same but with the English translation (translation was done after administration).
- The file 'Hooyberg_SurveyCoastalVisits_NL_print.pdf' clearly visualizes the layout and how the survey was shown to the respondents.
- The file 'Hooyberg_SurveyCoastalVisits_Qualtrics.qsf' is the Qualtrics project that can be loaded into the software.
- The file 'Hooyberg_SurveyCoastalVisits_translations_NL-EN.csv' contains the Dutch to English translations of the survey, which was downloaded from Qualtrics and which can be uploaded again if translations would have been lost in the Qualtrics project.

3.2. Folder '2. Raw data'

The raw data folder contains the raw survey responses (folder 'a. Survey responses'), the population statistics from which the weights were calculated (folder 'b. Population socio-demographics'), and the proxies for residential proximity to the coast derived by GIS (folder 'c. Residential distances to the coast').

3.2.1. Folder 'a. Survey responses'

The folder 'a. Survey responses' contains the complete and incomplete responses that were downloaded from Qualtrics at the end of the survey administration on January 18th 2023. Each folder has the responses in different formats: comma separated values format

(.csv), a format to be loaded in to IBM SPSS Statistics (.sav), tab-separated values format (.tsv), MS Excel standard format (.xlsx), and the MS Excel-compatible extensible mark-up language format (.xml).

3.2.2. Folder 'b. Population socio-demographics'

The folder 'b. Population socio-demographics' contains the original population statistics per stratum as originally received by Statbel (file 'Hooyberg_Pop_2023-08-01-Statbel.xlsx') and the re-formatted data in wide (file 'Hooyberg_Pop_2023-08-10_wide.xlsx') and long (file 'Hooyberg_Pop_2023-08-10_wide.xlsx') format to be loaded into R.

3.2.3. Folder 'c. Residential distances to the coast'

The different proxies for residential proximity to the coast are stored in two files. The first file ('Hooyberg_DistancesToNearestCoast.csv') contains a list of all the residential postal codes reported by the respondents and the corresponding distances to the nearest coast. The second file ('Hooyberg_DistancesToDestinations.csv') contains for each respondent the distances from the different types of residences to the visited seaside resorts. Both files were later merged with the survey data (see also section Methods – Additional calculations - 'Residential proximity to the coast').

3.3. Folder '3. Processing'

The processing folder contains the codebook and the folder 'R workspace'. The codebook ('Hooyberg_SurveyCoastalVisits_Codebook.csv') describes all of the original and newly added variables in the data with their coded names and formats. The folder 'R workspace' contains the latest version of the R script (named 'Hooyberg_SurveyCoastalVisits_2023-08-31.R'), the weights calculated from the population and sample statistics per stratum ('Weights.ISCEDLMH.Age.csv', see section Methods – Additional calculations - Weights), and the postal codes for the municipal seaside resorts ('Seaside_resorts_ZIP.csv'). The R workspace folder also contains the folder 'Adjustments'. This folder contains help files for correcting respondents' erroneous answers to the 'other' answer categories for household company ('Household_Company_other_adjustments.csv'), education level ('Education_other_adjustments.csv'), and occupational employment ('Employment_other_adjustments.csv'). The folder 'Adjustments' also contains the categorizations and translations of the chronic mental and physical illnesses reported by the respondents ('Chronics_mental_and_physical_illness_translation.csv'). Lastly, the 'Adjustments' folder contains two files that were used to identify the invalid responses by speeding and/or straight-lining. A first file contains all the complete responses (N = 1949) and was used to visually scroll through the data to search for patterns of speeding and/or straight-lining ('Survey_speeders_straightliners_highlighted.xlsx'). A second file contains the ID's of these invalid responses (N = 10) that were loaded into R for exclusion from the data ('Survey_speeders_straightliners_IDs.csv').

3.4. Folder '4. Processed data'

The folder '4. Processed data' harbors the final survey data in which the distances to the nearest coast are embedded (files 'Hooyberg_Survey_Processed.csv' and 'Hooyberg_Survey_Processed.txt'). It also contains the final distances data to the visited seaside resorts (files 'Hooyberg_Distances_Processed.csv' and 'Hooyberg_Distances_Processed.csv'). Both of these datasets were also merged together (file 'Hooyberg_Survey_Distances_Processed.csv' and 'Hooyberg_Survey_Distances_Processed.txt').

3.5. Folder '5. Figures'

The folder '5. Figures' contains the original figures included in this descriptor and their individual panels. The panels were imported in Adobe Illustrator (file 'Hooyberg_Survey_Descriptive_Graphs_2022-08-31.ai') and their format was clarified and made consistent for resulting in the final files for Figure 20, Figure 22, and Figure 23. The folder 'Raw figures from GIS' holds Figure 21 and all the original panels of Figure 23 that were generated via GIS. The folder 'Raw figures from GIS' also holds a figure overviewing all the primary and secondary residential postal codes in 2022 and those as a child. The folder 'Raw figures from R' contains the original panels of Figure 20 and Figure 22 that were generated and exported in R based on the survey data.

4. Technical Validation

4.1. Representativeness for the Flanders' population

The use of an access panel greatly increased the representativeness of the Flanders population compared to convenience or similar other survey sampling methods. It also ensured that all invited panelists were blinded for the survey topic to reduce selection-bias. However, the sample was not perfectly representative for the population based on age, gender/sex, educational attainment, and province of residence. In general, the majority of the strata were oversampled and the majority of the sampled individuals (77.6%) belonged to an oversampled stratum with a weight less than 1, which is consistent with what can be expected from the quota sampling procedure with oversampling allowance performed by the chosen panel provider. As a result, the data contains an overrepresentation of individuals that are 60-to-64-year-old, 40-to-49-year-old, belong to the middle socio-economic class, and reside in another province than Flemish Brabant (Figure 22 panels a and e). Underrepresented are the individuals that are 50-to-59-year-old, of lower socio-economic class, and who reside in Flemish Brabant (Figure 22 panels a and e). Also interesting was that 1 stratum had a weight of lower or equal than 0.2 that was assigned to 42 respondents (2.17%). Twenty-five strata had a weight higher or equal than 5 that was assigned to 5 respondents (0.26%). The data provided by the panel provider was insufficient to calculate design or non-response weights. It is difficult to compare the data about the coastal visits with other sources (e.g., by tourism agencies) because of the different sampling designs, different reference periods, and units of measurement.

4.2. Response quality

All original questions (in Dutch) with their best possible English translations can be found within the data (folder ‘1. Survey’), and any issues with regard to the quality of the responses can be attributed to the manner of asking the questions (Billiet & Waege, 2009; Schaeffer & Presser, 2003).

Only complete and valid responses were retained (N = 1939). Responses were regarded as complete when the last question of the survey was answered (N = 1949). Respondents that subsequently not proceeded to the end page or to the BPact panel user interface (N = 86) were retained, but note that these responses were not considered during the quota sampling and may have resulted in disproportional oversampling of the quotas (but see section Methods – Additional calculations – Weights and section Technical Validation – Representativeness for the Flanders’ population). Responses with relatively quick answering patterns (‘speeders’) and with repeated similar – often contradictory – answers (e.g., ‘always’ on all of the performed activities; ‘straight-liners’) were identified as invalid and were disregarded (N = 10). These invalid records were identified by searching through the data for records with the same responses throughout the survey. This process can be retraced in the file ‘Survey_speeders_straightliners_highlighted.xlsx’ in the folder ‘3. Processing/Adjustments’. We did not specify a cut-off on response times because case-by-case evaluation of the data by a researcher was more informative about the response quality. Section ‘Methods – Processing steps’ further provides what corrections were done to enhance the quality of the responses.

The proxies for residential proximity to the coast are based on residential postal codes, and not on accurate coordinates or addresses. As such, the user should keep in mind that the linear, shortest, and fastest travel routes reported in the data probably differ to a certain degree from the real routes.

5. Usage Notes

Familiarization with the survey design, questions, response options, and processing steps performed is encouraged before interpretation, exploration and analysis of the data. After familiarization, the final processed dataset can be explored and analyzed with the desired statistical software at any difficulty level to answer any of the research questions proposed in the introduction or other ones. Ideally, the survey weights are to be considered during the analyses, and the scope in time (i.e., 2022) and space (i.e., Flemish inhabitants and visits to the Belgian coast) should be respected during interpretation.

6. Code Availability

The software R (R-4.3.0, RStudio 2023.03.1+446; R Core Team, 2018) was used for processing the data. The R script can be found within the data (Hooyberg, Roose, et al., 2023) on location ‘/3. Processing/R workspace/ Hooyberg_SurveyCoastalVisits_2022-08-31.R’).

7. Acknowledgements

Respectful gratitude is given to Matty Vincke of the local coastal tourism agency Westtoer, who shared his valuable experiences and resources with regard to coastal tourism in the studied region. We would like to acknowledge the good and transparent services of the panel provider, Bpact.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Chapter VI

The social structuring of leisure activities and social company at the coast

Drafted for publication

Abstract

Research has shown that a person's health is linked to the amount of time spent at the coast. However, it is still unclear who performs what kinds of activities at the coast, with who, how frequently, and what experiences they result in. This study aimed to structure the domestic coastal leisure activities (e.g., walking at the beach) and the social company (e.g., with friends) with which they happen, and to assess how they covary with the visit frequency, season and type (i.e., day visits vs. longer stays) of coastal visits, the experiences gained (e.g., being fascinated), and the demographic, socio-economic, and health characteristics of the individuals in the Flanders' population in 2022. We addressed this aim by performing specific multiple correspondence analysis and ascending hierarchical cluster analysis on previously-gathered representative data of visitors to the Belgian coast (N = 1302). Four orthogonal dimensions were found to structure the variation in coastal leisure activities and social company on the basis of the level of self-reported frequency of engagement, whether the activities mainly happen in natural vs. urban environments, whether visitors usually come with partners or kids vs. with friends, a club, or no one, and whether the focus is on strengthening social bonds or exploring the coast. Five clusters of individuals could be distinguished in the multidimensional cloud: visitors with a 'generalist' activity pattern who are more likely to be middle-aged, higher educated adults with partners and kids; 'engagers in nature' who seem to have the coast embedded in their lifestyle and mainly do activities in natural environments at the coast; 'engagers in the city' who are more likely to be young (18-29y) or old (>=65y), physically active, higher educated, and frequent visitors of the coast that do not visit the coast in with family; 'disengagers in nature' who are more likely to be young, socially isolated individuals who explore nature at the coast alone; and 'disengagers in the city' who are more likely to be retired (>= 65y) off-season visitors with a partner that most often eat out and dwell in the coastal cities. Positive experiences happened less often when there is disengagement in natural environments at the coast, when the coast is not visited in a family context, and when the social company during the visit draws attention away from the environment. The surfaced multidimensional associations highlight the importance of considering both activity-related and social factors and calls to adopt both epidemiological and socio-behavioral perspectives when assessing the effects of the coast on human health.

Keywords

Blue Space, Social Company, Bourdieu, Health, Visits

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1. Introduction

Coastal environments have historically grown to become a highly popular destination for leisure (Charlier & Chaineux, 2009; Northrop et al., 2022). Recent cross-country analyses has shown that people living closer to the coast visit it more often and gain more benefits for health (Elliott et al., 2023; Geiger et al., 2023). Now, it is time to redirect the research towards understanding who performs what activities at the coast and how these activities impact health differently.

Coastal visits may happen with a particular frequency and duration and involve different sets of activities and social company. They may involve a short visit as part of a day trip or it may be part of a longer holiday that involves an overnight stay in an accommodation at the coast. All of these visit characteristics would match with the demographic, socio-economic, and health profile of the visitor (Boyd et al., 2018; Elliott et al., 2018). Depending on the specific activity, different health effects may be experienced. More specifically, it is widely accepted that leisure activities have additional benefits for health if they happen more frequently, if they occur in a relatively natural environment, if the weather is comfortable, if it involves some level of physical intensity, and happens alone, or with others when safety is a concern (Ashbullby et al., 2013; Hartig et al., 2014; Hooyberg, Michels, et al., 2022; Johansson et al., 2011; Staats & Hartig, 2004; White et al., 2020; White, Pahl, et al., 2016; Wyles et al., 2016). Coastal visitors have reported several positive experiences, such as lower levels of stress, a more positive mood, feeling cognitively restored, feeling less negative physiological arousal, and enriched dimensions of well-being (S. L. Bell et al., 2015; Hooyberg, Michels, et al., 2022, 2023; Severin et al., 2022; Wilczyńska et al., 2023). So, there is a relatively good understanding of the range of leisure activities performed in coastal environments and the range of experiences to be potentially gained. However, it is still unclear whether there are underlying patterns in the clutter of coastal visits and visitors, whether distinct visit profiles can be distinguished, and how coastal visits and the activities during these visits are socially structured.

Studies have shown that leisure activities, such as coastal visits, are deeply entrenched in an individual's lifestyle habits (Roose et al., 2014). Different frameworks have theorized what motivational, practical, and social reasons might explain an individual's leisure activity pattern, such as the reasoned action approach (Ajzen, 1991; Ajzen & Driver, 1992; Conner et al., 2017; McEachan et al., 2016), the expectancy-value principle (Eccles & Wigfield, 2020; Van Der Pligt & De Vries, 1998), leisure constraints theory (D. W. Crawford et al., 1991; Dean et al., 2022; Shores et al., 2007), health belief model (Carpenter, 2010; Rosenstock, 2005) and Bourdieu's distinction theory (Bourdieu, 1984). In this study, Bourdieu's distinction theory was applied on coastal leisure activities. Bourdieu postulates that an individual's behavior, or *habitus* (i.e., in this case, coastal leisure activities), occurs within a social *field* (i.e., the specific geo-cultural region that acts on an individual's behavior) in which all individuals have to adhere to factors outside the individuals' control (e.g., the weather, the behavior of other individuals; Bourdieu, 1984). According to Bourdieu, each individual constantly exhibits behaviors to strengthen its belonging to a particular group of individuals within the field while distancing itself from other groups. The individual's position or status within the social field is determined by that individual's habitus, which in turn is tethered to that individual's social, cultural, and economical capital (Kandt, 2018; Roose et al., 2014; Rosenlund, 2017; Weininger, 2010). Social capital relates to how an individual can rely on family and friends in daily life and when serious problems are faced, economical capital to an individual's financial status, such as income, and cultural capital to an individual's previous experiences, educational attainment, and cultural taste. Health capital is another capital that has been brought up recently (Schneider-Kamp, 2021), and also seems a relevant determinant for behavior at the coast, because coastal environments have often been visited for relaxation and gaining benefits for mental and physical health (S. L. Bell et al., 2015; Charlier & Chaineux, 2009; Gammon & Jarratt, 2019). Thus, applied to coastal environments, visitors would generally perform mostly those coastal leisure activities that fit with their social status and capital. Translating this rationale to an epidemiological context, the coastal leisure activities that a visitor performs would be associated with its demographic, socio-economic, and health background (i.e., related to social status and capital). Furthermore, the frequency, season, and type (e.g., day visit or longer stay) of the visits would be a reflectance of how the visitor deals with the accessibility to the coast and of the trade-off between the benefits of the visits for the visitor and the visitor's time and resources it is willing to spend to gain those benefits (i.e., related to the field). The coast can be visited alone or with others, and the social company during the visit may be both an indication of the visitor's social status as well as how the visitor has consciously or unconsciously outweighed maintaining social relationships with pursuing own desires and motivations. Thus, the set of coastal leisure activities and the social company during those visits is likely to covary with the visitor's experiences, individual characteristics, and the season, frequency, and type of the visits.

This study aimed to explore the patterning of coastal leisure activities and their social structuring, while considering Bourdieu's distinction theory. To do this, specific Multiple Correspondence Analysis (MCA) and Ascending Hierarchical Cluster (AHC) analysis were applied on coastal visit data from the Flemish population in 2022. These methods are particularly useful for examining (coastal) leisure activities, because they allow to surface the underlying multivariate dimensions (MCA) and clusters (AHC) that give structure and meaning to the masses (Hjellbrekke, 2018; LeRoux & Rouanet, 2010). Both of these methods consider that variation in behavior on both an individual and activity-level is omnipresent and that behaviors are exhibited along a continuum of taste vs. distaste. A first step in a specific MCA typically involves the construction of a multidimensional map that structures the variability in the main variables of interest, i.e., usually those referring to the actual behavior (Hjellbrekke, 2018). Therefore, the MCA identifies orthogonal dimensions along which the categories of these main variables, as well as the individuals, can be structured. In this study, the first target was to structure the activities undertaken at the coast and the social company they were with (Figure 24). The activities inherently contained information about the environmental and physical context in which they occurred (e.g., 'walking at the beach', 'exploring the city'). The MCA should surface the environmental, physical, and social visit characteristics that matter most for structuring the activities. In a second step, supplementary variables can be plotted onto the multidimensional map without them contributing to defining it (Hjellbrekke, 2018). In this study, the second target was to reveal how the coastal leisure activities and social company covary with the season, frequency, and type (i.e., day visits vs. longer stays) of coastal visits, the experiences gained, and the demographic, socio-economic, and health characteristics of the individuals (Figure 24). Note that the season, frequency, and type of coastal visits also could have been considered as coastal visit behavior and thus as main variables. However, they were taken as supplementary variables, because in the context of Bourdieu's distinction theory, the coastal leisure activities (e.g., 'sunbathing') are the eventual behavior, and the season, frequency, and type of visits are a means to achieve that behavior, and are thus subordinate and should not contribute to defining the space. In a third and last step, the AHC can take the coordinates of the individuals in the map to define clusters of individuals that relatively covary with each other along the orthogonal dimensions (Hjellbrekke, 2018). In this study, the third target was to identify clusters of individuals with similar leisure activity profiles and to describe them based on their locations in the multidimensional space and their association with the supplementary variables (Figure 24). Thus, this study identified and described orthogonal dimensions that structure the coastal leisure activities and social company, linked these dimensions to the season, frequency, and type (i.e., day visits vs. longer stays) of coastal visits, the experiences gained, and the demographic, socio-economic, and health characteristics of the individuals, and defined clusters of individuals who exhibit a similar coastal leisure activity pattern.

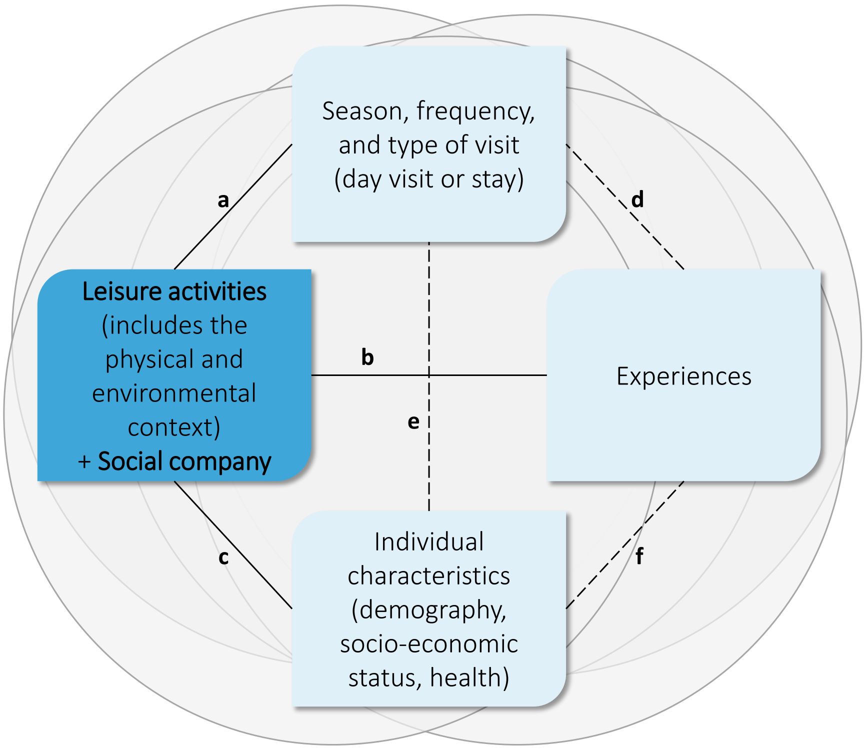

Figure 24: Graphical overview of this study's aims. First, the coastal leisure activities and social company were structured along orthogonal dimensions. Second, the supplementary variables were mapped onto these dimensions, these variables were the season, frequency, and type of visit, the experiences, and the individual characteristics, from which the direct associations a, b, and c should emerge. The resulting map should also allow to formulate associations among the supplementary variables (dashed lines d,

e, and f). Third, clusters of individuals were defined with similar coastal leisure activity profiles and other characteristics.

2. Materials and methods

2.1. Data and recoding

Data was drawn from a cross-sectional survey about the domestic coastal visit behavior of Flemish inhabitants in the year 2022 (N = 1939). The data collection, quality, and univariate trends in the data are described in the previous chapter (Chapter V).

The focus was on respondents that visited the coast during the last year (N = 1302, 67%). Data was extracted about how often these visitors performed 32 activities, how often they were with 7 types of social company, the number of days spent at the coast during the previous year (i.e., 'Visits_Days'), whether they were at the coast as a recreational day visit or when staying in an accommodation during every of the four seasons in 2022 (e.g., variable 'Visits_Days_Daily_Spring'; with categories yes and no), had 27 experiences, and the demographic, socio-economic, and health background (Table 13, Table 14). The different types of activities, social company, and experiences were rated on a five-point Likert scale with answers 'always', 'often', 'sometimes', 'seldom', and 'never'. Similar as in previous research, we dichotomized these ratings into a 'yes' category for 'always', and 'often' and a 'no' category for 'sometimes', 'seldom', and 'never' (Table 13; Hjellbrekke, 2018; Roose et al., 2014). As such, the idea was to enable the analyses to distinguish activities that are clearly favored and are thus performed often or always. The included experiences referred to perceptions about psychological and physical changes during the visit that have been described in the literature for being contributive to health (White et al., 2020). The following demographic, socio-economic, and health characteristics were also included in our analyses: age (18-29y, 30-39y, 40-49y, 50-59y, 60-64y, >=65y), gender (male, female, Other/rather not say), province (Flemish Brabant, Antwerp, Limburg, West-Flanders, East-Flanders, NA), perceived residential distance to the coast (>100km, 50-100km, 20-50km, 5-20km, <5km), number of co-inhabitants ('household number'; 0, 1, >1), relation with co-inhabitants (Partner: Yes/No; Parents or Grandparents: Yes/No; Children: Yes/No; Other Family members: Yes/No; Friends: Yes/No), owning a holiday residence at the coast (Yes, No), having grown up in Belgium (Yes, No), number of people that the respondent could go to when facing serious problems ('social support'; 0-1, 2-5, >5), perceived average number of days per year at the coast before the age of 12 ('visits as a kid'; 0-2, 3-5, >5), employment time (full-time, part-time), educational attainment according to the International Standard Classification of Education (ISCED; 0-2, 3-4, 5-8), employment status (Active, Inactive), having an employment that requires the respondent to be at least 'sometimes' at the coast (yes, no), household income (<2000€/month, 2001-3000€/month, 3001-4000€/month, 4001-5001€/month, >5001€/month), self-reported general health according to the 1-item short form questionnaire (SF1; very good, good, moderate, (very) bad), mental health based on the mental health-related questions of the Short-Form-36 (SF36MH; <Q1, Q1-Q2, Q2-Q3, >Q3 where Q1-3 refer to the first, second, and third quantiles) and subdivisions of emotional health (<Q1, Q1-Q2, Q2-Q3, >Q3) and vitality (<Q1, Q1-Q2, Q2-Q3, >Q3), and physical activity level according to the short form of the international physical activity questionnaire (<Q1, Q1-Q2, Q2-Q3, >Q3).

Table 13: Frequency table of the main variables.

Activity	Yes	No	Social company	Yes	No
HaveAGoodTalk	0.891	0.109	WithPartner	0.715	0.285
StrollOnDike	0.889	0.111	WithFriends	0.475	0.525
TerraceTearoomCafe	0.876	0.124	WithKids	0.452	0.548
WalkingAtBeach	0.875	0.125	WithFamily	0.438	0.562
Restaurant	0.849	0.151	WithParentsGrandparents	0.248	0.752
TakingPictures	0.805	0.195	Alone	0.187	0.813
ExploringCity	0.737	0.263	WithClub	0.092	0.908
WalkingInDunes	0.712	0.288			
Pier	0.697	0.303			
DrinkAlcohol	0.625	0.375			
WindowShopping	0.598	0.402			
WatchSunset	0.562	0.438			
Seagoing	0.549	0.451			
SpendTimeOnBeach	0.528	0.472			
BeachBar	0.512	0.488			
HistoryMonumentExhibitionMuseum	0.448	0.552			
Picknick	0.44	0.56			
SearchingShells	0.435	0.565			
PlayWithKids	0.408	0.592			
WatchBotes	0.406	0.594			
VisitingFriend	0.365	0.635			
Cycling	0.353	0.647			
WildlifeSpotting	0.308	0.692			
ShowsFestivals	0.278	0.722			
VisitingFamily	0.247	0.753			
TakingTheDog	0.193	0.807			
RentGoCart	0.186	0.814			
BeachSports	0.132	0.868			
Watersports	0.122	0.878			
Jogging	0.104	0.896			
RentALounge	0.083	0.917			

Table 14: Frequency table of the supplementary variables. SES = socio-economic status. ISCED = International Standard Classification of Education. SF = Short form health survey. MH = Mental health.

* For variables with only the categories Yes and No, only the frequency of the Yes category is shown. The frequency of the No category can be calculated by subtracting 1 with the frequency of the Yes category.

Type	Variable	Category	Frequency
Activities	Mountainbiking	Mountainbiking_Y*	0.04
Visits	Visits_Days	DaysAtCoast_1	0.10
		DaysAtCoast_2-3	0.41
		DaysAtCoast_4-7	0.22
		DaysAtCoast_>8	0.27
	Visits_Days_Daily_Fall	DayVisits_Fall_Y*	0.33
	Visits_Days_Daily_Spring	DayVisits_Spring_Y*	0.45
	Visits_Days_Daily_Summer	DayVisits_Summer_Y*	0.55
	Visits_Days_Daily_Winter	DayVisits_Winter_Y*	0.36
	Visits_Days_Stays_Fall	StayVisits_Fall_Y*	0.19
	Visits_Days_Stays_Spring	StayVisits_Spring_Y*	0.26
	Visits_Days_Stays_Summer	StayVisits_Summer_Y*	0.36
	Visits_Days_Stays_Winter	StayVisits_Winter_Y*	0.20
Experiences	BeingAway	BeingAway_Y*	0.90
	BeingBored	BeingBored_Y*	0.12
	BeingFascinated	BeingFascinated_Y*	0.83
	BeingInAwe	BeingInAwe_Y*	0.74
	BeingRelaxed	BeingRelaxed_Y*	0.97
	ConnectingWithNature	ConnectingWithNature_Y*	0.83
	EnjoyingExtent	EnjoyingExtent_Y*	0.82
	EnjoyingOffSeasonCalmness	EnjoyingOffSeasonCalmness_Y*	0.86
	EnjoyingSandToes	EnjoyingSandToes_Y*	0.56
	EnjoyingSeaAir	EnjoyingSeaAir_Y*	0.96
	EnjoyingSoundOfWaves	EnjoyingSoundOfWaves_Y*	0.90
	EnjoyingSummerCrowding	EnjoyingSummerCrowding_Y*	0.37
	EnjoyingTheView	EnjoyingTheView_Y*	0.95
	FeelingActive	FeelingActive_Y*	0.78
	FeelingAnxious	FeelingAnxious_Y*	0.06
	FeelingAtHome	FeelingAtHome_Y*	0.79
	FeelingCompatible	FeelingCompatible_Y*	0.79
	FeelingFree	FeelingFree_Y*	0.90
	FeelingHappier	FeelingHappier_Y*	0.88
	FeelingPhysicalRest	FeelingPhysicalRest_Y*	0.87
	GainingSelfConfidence	GainingSelfConfidence_Y*	0.60
	HavingHolidayVibes	HavingHolidayVibes_Y*	0.89
	HavingPeaceOfMind	HavingPeaceOfMind_Y*	0.90
	LosingTrackOfTime	LosingTrackOfTime_Y*	0.78
	ProblemSolving	ProblemSolving_Y*	0.44
	RecallingMemories	RecallingMemories_Y*	0.67
	SituateFeelingsThoughts	SituateFeelingsThoughts_Y*	0.74
Demography	Age	18-29y	0.16
		30-39y	0.17
		40-49y	0.20
		50-59y	0.13
		60-64y	0.14
		>=65y	0.19
	Gender	Male	0.48
		Female	0.52
		Gender_other/rathernotsay	0.01
	Province	FlemishBrabant	0.06
		Antwerp	0.24
		Limburg	0.20
		WestFlanders	0.23

		EastFlanders	0.27
		NA	0.00
	DistanceToCoast_Perceived	>100km	0.45
		50-100km	0.29
		20-50km	0.13
		5-20km	0.06
		<5km	0.07
	Household_number	Household_0	0.14
		Household_1	0.33
		Household_>1	0.53
	Household_With.one.or.more.children	Household_Children_Y*	0.05
	Household_With.one.or.more.friends	Household_Friends_Y*	0.01
	Household_With.one.or.more.other.family.members	Household_Family_Y*	0.02
	Household_With.one.or.more.parents	Household_Parents_Y*	0.05
	Household_With.partner	Household_Partner_Y*	0.37
	CoastalHolidayResidence	CoastalHolidayResidence_Y*	0.10
	Kid_Belgium	Belgian	0.97
		Immigrant	0.03
	SocialSupport	SocialSupport_0-1	0.11
		SocialSupport_2-5	0.56
		SocialSupport_>5	0.33
	VisitsKid	VisitsKid_0-2	0.30
		VisitsKid_3-5	0.19
		VisitsKid_>5	0.51
		NA	0.00
	EmploymentTime	Full-time	0.41
		Part-time	0.10
		NA	0.49
SES	Education_ISCED	ISCED0-2	0.13
		ISCED3-4	0.44
		ISCED5-8	0.42
		NA	0.01
	Employment	Employment_Active	0.60
		Employment_Inactive	0.40
	Employment_Coast	Employment_Coast_Y*	0.08
	HouseholdIncome	<2000€/month	0.20
		2001-3000€/month	0.24
		3001-4000€/month	0.23
		4001-5001€/month	0.16
		>5000€/month	0.15
		NA	0.02
Health	SF1_GeneralHealth	SF1_Verygood	0.18
		SF1_Good	0.48
		SF1_Moderate	0.26
		SF1_(Very)bad	0.08
	SF36MH.mean	SF36MH_<Q1	0.25
		SF36MH_Q1-Q2	0.24
		SF36MH_Q2-Q3	0.28
		SF36MH_>Q3	0.22
	SF36MH.Emotional.mean	Emotional_<Q1	0.24
		Emotional_Q1-Q2	0.30
		Emotional_Q2-Q3	0.28
		Emotional_>Q3	0.18
	SF36MH.Vitality.mean	Vitality_<Q1	0.24
		Vitality_Q1-Q2	0.26
		Vitality_Q2-Q3	0.32
		Vitality_>Q3	0.18
	PhysicalActivity	PhysicalActivity_<Q1	0.23
		PhysicalActivity_Q1-Q2	0.25
		PhysicalActivity_Q2-Q3	0.26
		PhysicalActivity_>Q3	0.27

2.2. Analyses

2.2.1. Aim 1: Structuring of coastal leisure activities and social company

A specific MCA was used to identify dimensions that structure the coastal leisure activities and social company. MCA is a multivariate geometric data analytical tool that is based on a contingency table with the relative frequencies of individuals and categories. These categories are the factor levels of the main categorical variables (e.g., variable ‘walking at the beach’ has categories ‘yes’ and ‘no’) (Greenacre & Blasius, 2006; Hjellbrekke, 2018; LeRoux & Rouanet, 2010; Nenadic & Greenacre, 2011). In a specific MCA, only categories with a relative frequency between 95% and 5% are considered. As such, a specific MCA avoids that rare or ubiquitous categories would unrightfully dominate the multidimensional structuring. Only the activity ‘Mountainbiking’ did not meet this criterion, and was thus set as supplementary (Table 13, Table 14). Based on the contingency table, weighted Chi-Square distances are calculated based on the individuals’ and categories’ frequencies and size. Subsequently, these distances are plotted in a multidimensional space, with similar individuals and categories close to each other and dissimilar ones further apart. The average profile is represented at the center of the cloud, or ‘barycenter’, and the most distinctive individuals and categories are furthest away from the barycenter. Finally, each axis in the MCA is rotated around the barycenter to find the most optimal explanatory power, whereby each axis must be orthogonal to the other axes and thus explain the variation in the data in a different way. The strength by which an axis explains the variation in the individuals and categories is quantified by its eigenvalue, denoted by λ, and all eigenvalues sum up to the total inertia in the data. There are many variations and extensions on the method, and in this study, we follow the recommendations outlined by Hjellbrekke (2018).

To address the first aim of this study, the space was defined based on the activities that people perform at the coast (these variables also hint at the environment and level of physical activity) and the social company with who they perform these activities (i.e., with main categories ‘yes’ and ‘no’; Table 13). The most important dimensions were identified on the basis of the dimensions’ eigenvalues and the explained inertia (using the Greenacre method; Greenacre, 2002). Interpretations were only made about those categories that contributed above average to the dimension.

2.2.2. Aim 2: Association with supplementary variables

Whereas the main variables in an MCA define the structuring of the dimensions, supplementary variables can be plotted onto the space without them contributing to defining the space. For the second aim of this study, the categories of the supplementary variables were mapped onto each dimension. These variables included those that referred to the number of days spent at the coast, the day visits and stays per season, the experiences, and the demographic, socio-economic, and health characteristics. Since there were many supplementary categories, typicality tests were run based on the z statistic to focus only on those categories of which the coordinates significantly differed from the barycenter

(Hjellbrekke, 2018, p. 68-69). Furthermore, categories that were beyond the average absolute supplementary coordinate were disregarded.

2.2.3. Aim 3: Defining clusters

The coordinates of the individuals in the multidimensional space were used in an AHC analysis. AHC analysis performs stepwise clustering of individuals that occur closely together in the multidimensional space and are thus more similar to each other than other individuals (Hjellbrekke, 2018). During each iteration in an AHC analysis, one cluster is merged with another, and the number of clusters, denoted by k, diminishes by 1. During each iteration, the ratio of the between-cluster variance to the total variance, denoted by η^2, drops proportionately to the dissimilarity between the joined clusters. To address the third aim of this study, a dendrogram and a plot showing how η^2 changes with k were used to define the optimal number of clusters for further examination. Subsequently, the clusters' locations, forms, and sizes in the multidimensional space were depicted by means of concentration ellipses, which typically sum up approximately 2 standard deviations in a two-dimensional distribution, thus containing 86.47% of the data (Hjellbrekke, 2018). The over- or under-representativeness of each main and supplementary category was examined by tabulating the ratio of the frequency in the cluster relative to in the sample. The p-value of Chi-Square-tests ($\alpha = 0.05$) was used to focus on those categories of which the frequency in the cluster differed from that in the sample. The analyses were performed in R (R Core Team, 2023) with packages '*factoextra'* for the specific MCA (Kassambara & Mundt, 2020) and '*cluster'* for the AHC analysis (Maechler et al., 2022).

3. Results

3.1. Structuring of coastal leisure activities and social company (aim 1) and associations with supplementary variables (aim 2)

The specific MCA resulted in four relevant dimensions (Figure 25). The first dimension was by far the most explanatory (Greenacre inertia = 47.36%) and the subsequent three dimensions had Greenacre inertia of 10.00%, 5.53%, and 4.27%, respectively. Together, these four dimensions explain 67.16% of the variation in the data. From dimension 5 onwards, the explained variation was considered too small for any relevant conclusions to be made. Another reason of retaining dimension 4, and not 5, is that the categories on dimension 4 still revealed a comprehensible pattern, as is demonstrated later, and dimension 5 not (Figure S 41).

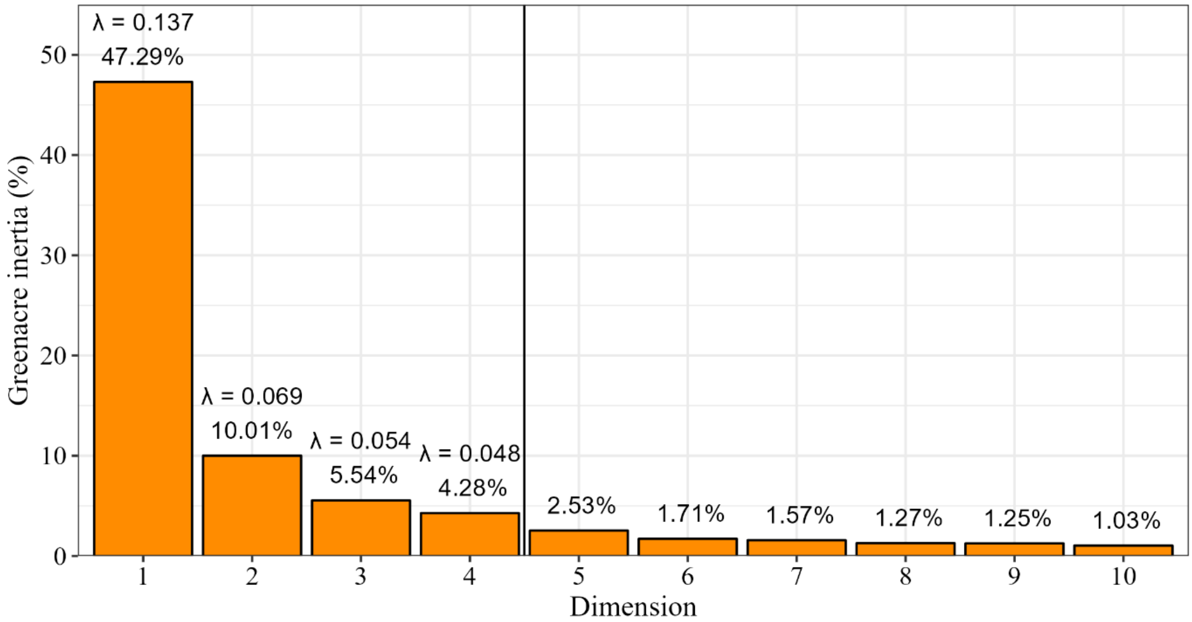

Figure 25: Overview of the Greenacre inertia (%) of the first 10 dimensions identified by the specific MCA. The vertical line separates the first 4 dimensions of interest from the remaining dimensions. The eigenvalues (λ) are also depicted for the first four dimensions.

3.1.1. Dimension 1: disengagement (left) – engagement (right)

The first dimension structured the data along an axis of engagement vs. disengagement (Figure 26, Table S 25). Engagement is depicted on the right side by activities and social company that are often or always performed, whereas disengagement is depicted on the left side by activities and social company that are sometimes, seldom, or never performed. This axis shows at the extremes the behaviors that are the most distinctive (see also Figure 20 in Chapter V). Particularly, renting a lounge, doing water- or beach-sports, and renting a go cart is distinctive, as well as not going to a terrace, tearoom café or restaurant, not strolling on the dike, not having a good talk, and not walking at the beach (Figure 26 and Table S 25, see also Figure 20 in Chapter V). The categories that contribute above average on this axis explain 78.32% of the variance along this axis.

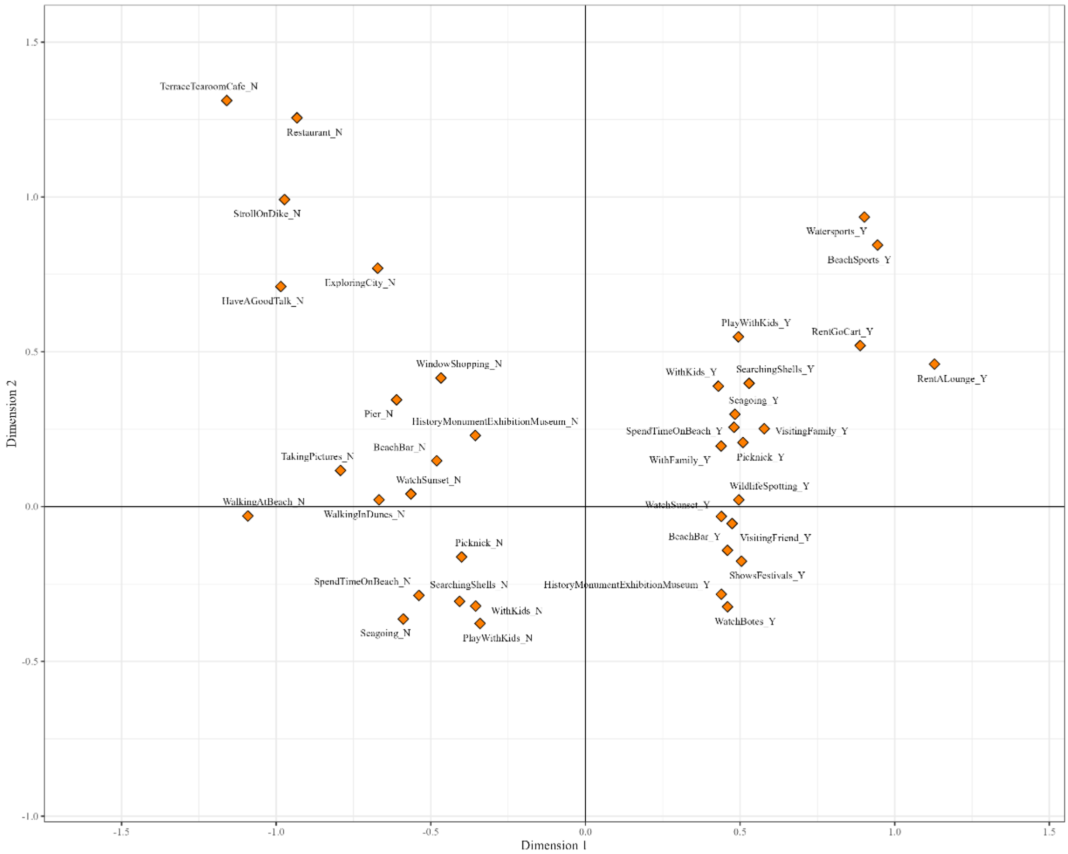

Figure 26: Plane of dimension 1 and 2 with the main categories that contribute above average to dimension 1.

The supplementary categories show that engagement-disengagement structure in coastal leisure activities coincides with a similar pattern in the experiences, the time that an individual is at the coast, and the level of social isolation (Figure 27). More specifically, the engagement side of the axis coincides with spending more than 8 days at the coast, residing at or work with the coast, or staying in a holiday residence at the coast that is owned or rented. In contrast, the left disengagement side covaries with being socially isolated (i.e., living alone, having little social support). Further, the disengagement side depicts experiences that are gained less than often, while the right side experiences that are gained often or always. For example, disengaging with the coast covaries with not enjoying the view, sea air, or sound of waves, not being relaxed, and not feeling holiday vibes. Alternatively, engaging with the coast covaries with enjoying the summer crowding and the sand between the toes, problem solving and gaining self-confidence, but also with feeling anxious.

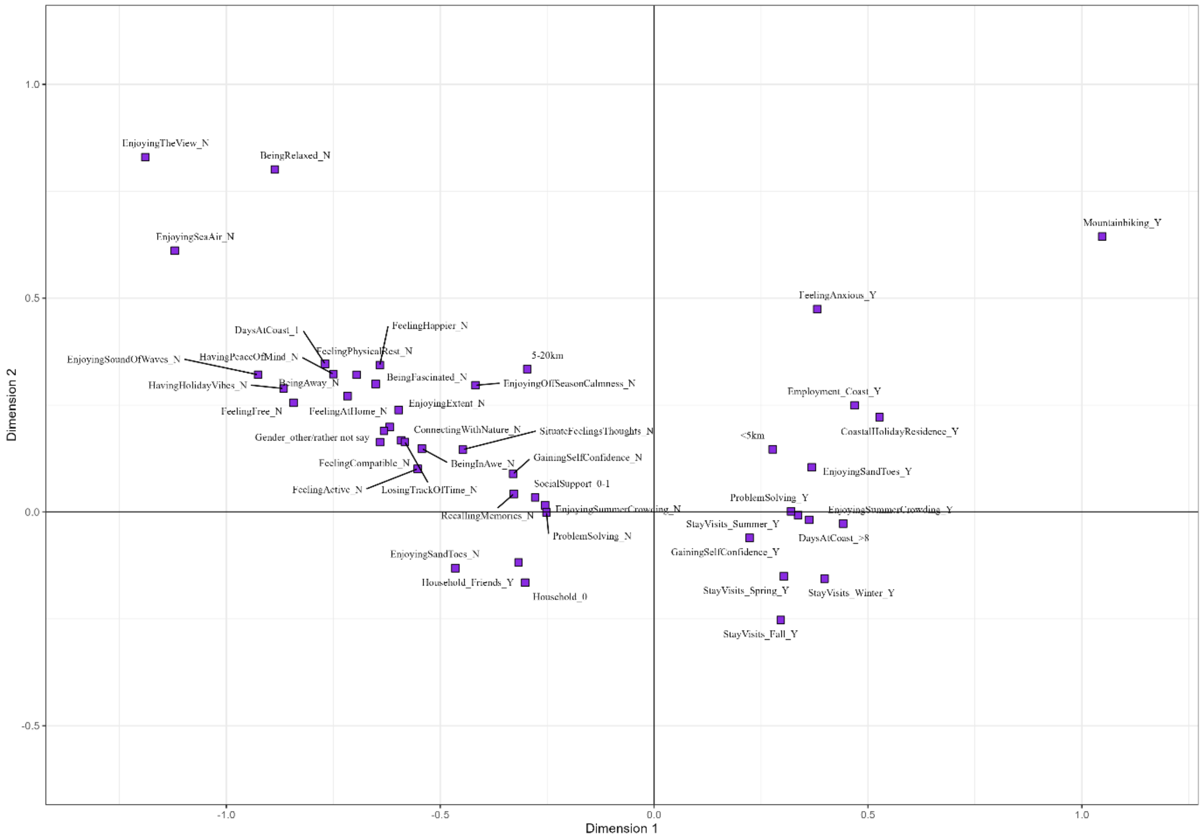

Figure 27: Plane of dimension 1 and 2 with the supplementary categories of which the coordinates on dimension 1 are different from 0 (based on typicality tests) and are above the average of the absolute coordinates on dimension 1.

3.1.2. Dimension 2: urban (bottom) – natural (top)

The second dimension separates on the basis of whether coastal visits generally involve activities in urban or natural environments (Figure 28, Table S 26). The top side depicts that it is highly distinctive to not do urban-based activities, such as not eating out, not strolling on the dike, not exploring the city, not drinking alcohol, or not doing window-shopping. Not doing these urban activities covaries well with doing nature-related activities with children or parents, spending time on the beach or in sea, searching shells, or doing water- and beach-sports. Whereas these nature-oriented behaviors seem to be relatively distinctive (i.e., they contribute relatively strongly to defining the dimension, Table S 26), the bottom side depicts less distinctive urban-based activities, such as such as exploring the city, visiting cultural exhibitions, not spending time on the beach or in sea, or not visiting with kids. The categories that contribute above average on this axis explain 85.77% of the variance along this axis.

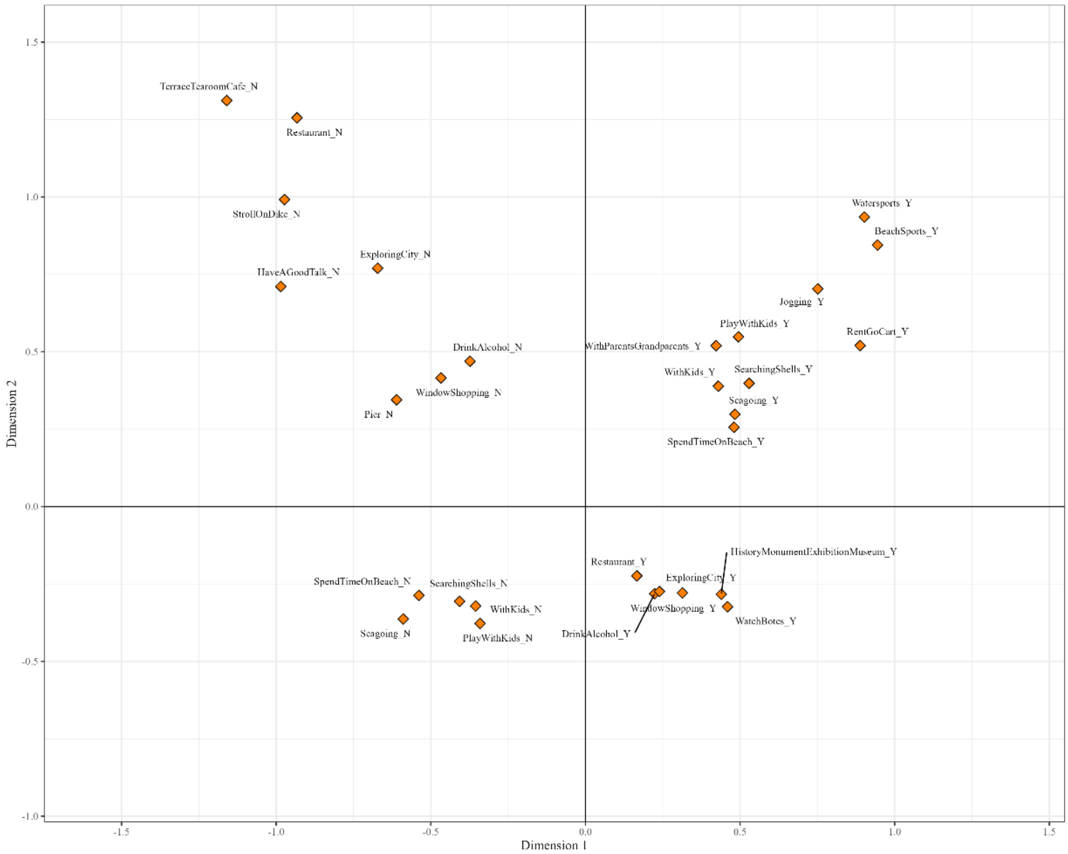

Figure 28: Plane of dimension 1 and 2 with the main categories that contribute above average to dimension 2.

Activities in natural coastal environments and with family are typically associated with gaining positive experiences less often and feeling bored or anxious more often (Figure 29). They are typically done by adults below the age of 50 who visit the coast once a year, live within 20 km off the coast, own a holiday residence at the coast, or have work related to the coast. They have attained a relatively high educational degree, and often live with children and other family members. Remarkably, these individuals tend to have a relatively low mental health. In contrast, activities in urban coastal environments are associated with gaining positive experiences infrequently. These urban activities are particularly done by older adults who live further away from the coast (i.e., >100km), are not employed, have a low educational attainment, live alone or with their partner, have stayed in an accommodation outside the summer season, or are in relatively very good health.

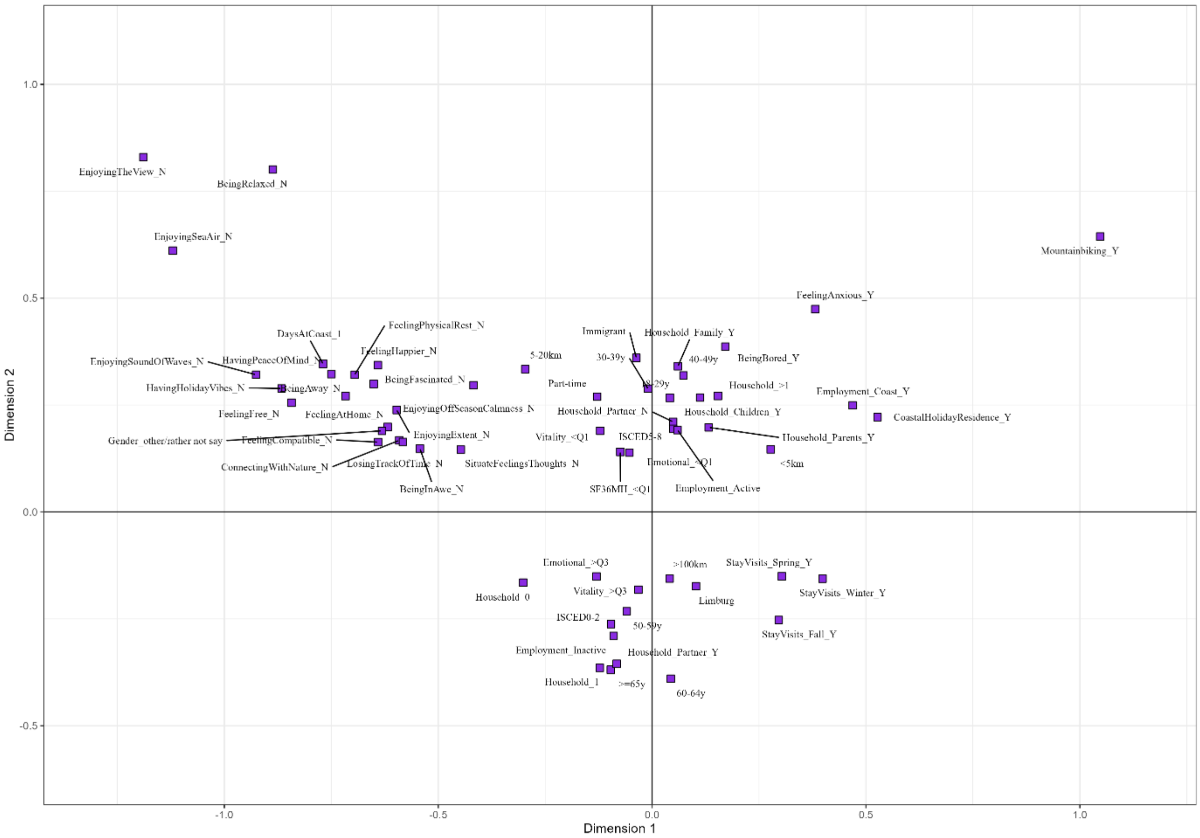

Figure 29: Plane of dimension 1 and 2 with the supplementary categories of which the coordinates on dimension 2 are different from 0 (based on typicality tests) and are above the average of the absolute coordinates on dimension 2.

3.1.3. Dimension 3: with partner and kids (bottom) vs. alone or with friends (top)

The third dimension opposes categories on the basis of the social company and what can be done with them (Figure 30, Table S 27). More specifically, the bottom side of the dimension differentiates activities with partner and kids, such as searching shells. At the top side, it differentiates activities that are performed alone, with a friend, or with the club, such as doing sports, going to shows and festivals, or visiting a friend or family. Being accompanied by friends does not seem to be compatible with being accompanied by the partner and kids at the coast and vice versa. The categories that contribute above average on this axis explain 84.90% of the variance along this axis.

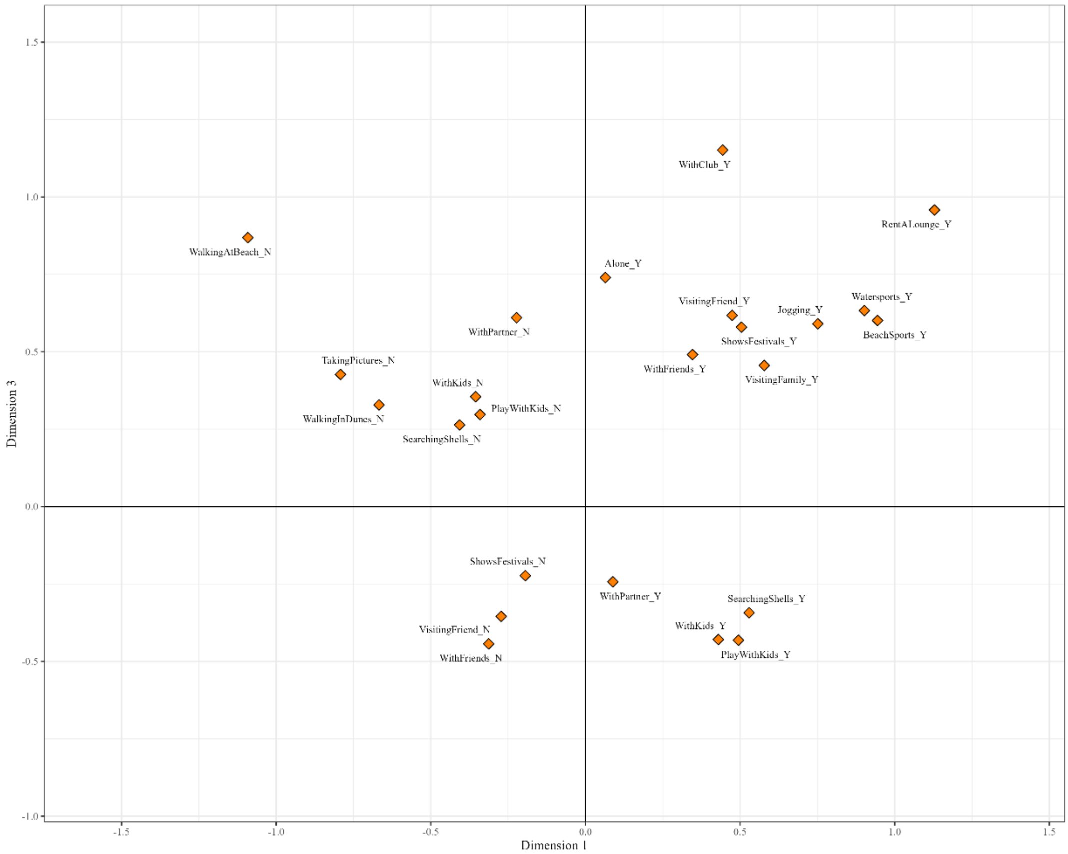

Figure 30: Plane of dimension 1 and 3 with the main categories that contribute above average to dimension 3.

Visiting the coast with partner and kids is typically performed by middle-aged adults with a moderate to high income and who work part-time (Figure 31). In contrast, the activities that happen alone, with friends, or with the club (i.e., sports, going to shows or festivals, or visiting family) often co-occur with feelings of anxiety and boredom, and less often with the many positive experiences included in the analysis. These activities typically happen by young adults who live alone or still live with their parents or other family members, and who tend to have little social support, have a low income, have a low emotional health, but are highly physically active.

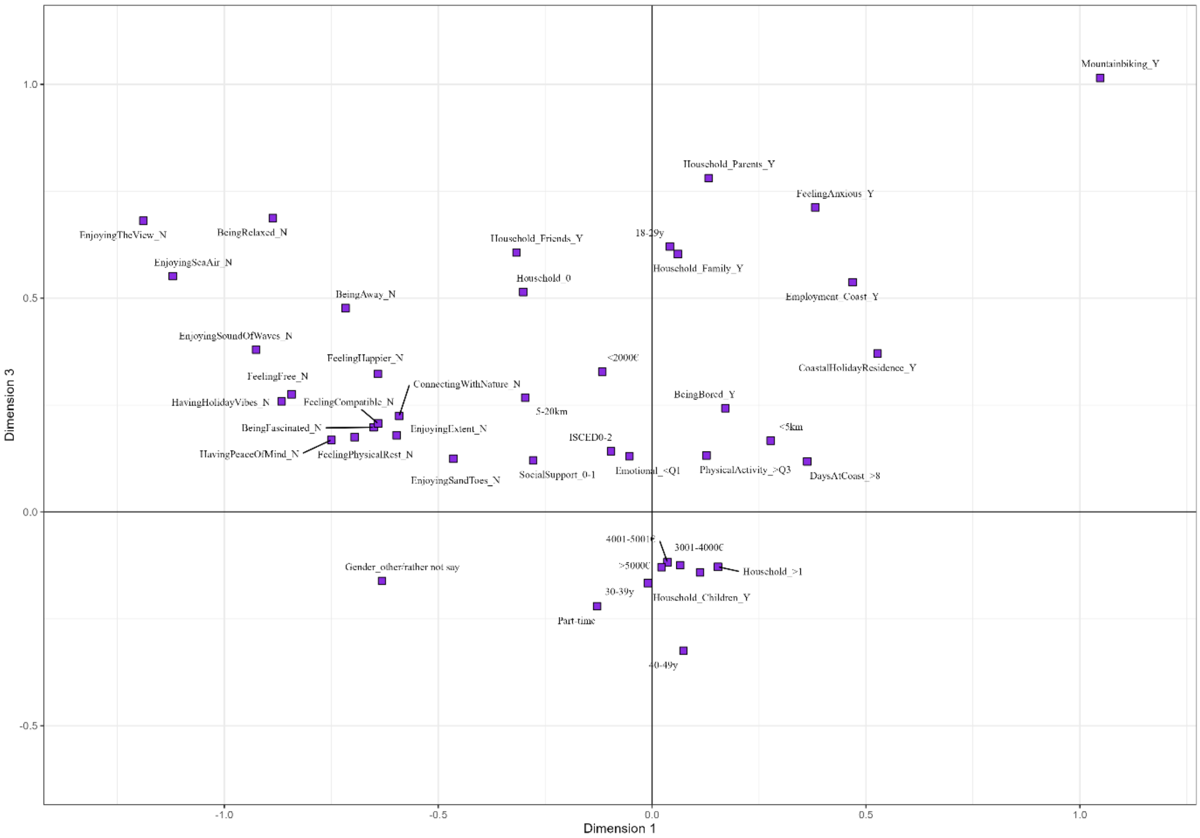

Figure 31: Plane of dimension 1 and 3 with the supplementary categories of which the coordinates on dimension 3 are different from 0 (based on typicality tests) and are above the average of the absolute coordinates on dimension 3.

3.1.4. Dimension 4: visiting family or a friend (bottom) – exploring (top)

The fourth and last relevant dimension hints to the underlying reasons for visiting the coast (Figure 32, Table S 28). At the bottom, the activities mainly involve visiting family or a friend. These activities are typically done with the partner and kids, and do not involve walking at the beach or dunes, visiting a pier, watching the sunset, or spotting wildlife. At the top side, the dimension depicts exploring the coast, typically alone or with the club, such as by spotting wildlife, watching the sunset, walking in dunes, and visiting cultural exhibitions. These activities seem to be relatively incompatible with eating out, having a good talk, drinking alcohol, and taking along the partner or kids. The categories that contribute above average on this axis explain 82.82% of the variance along this axis.

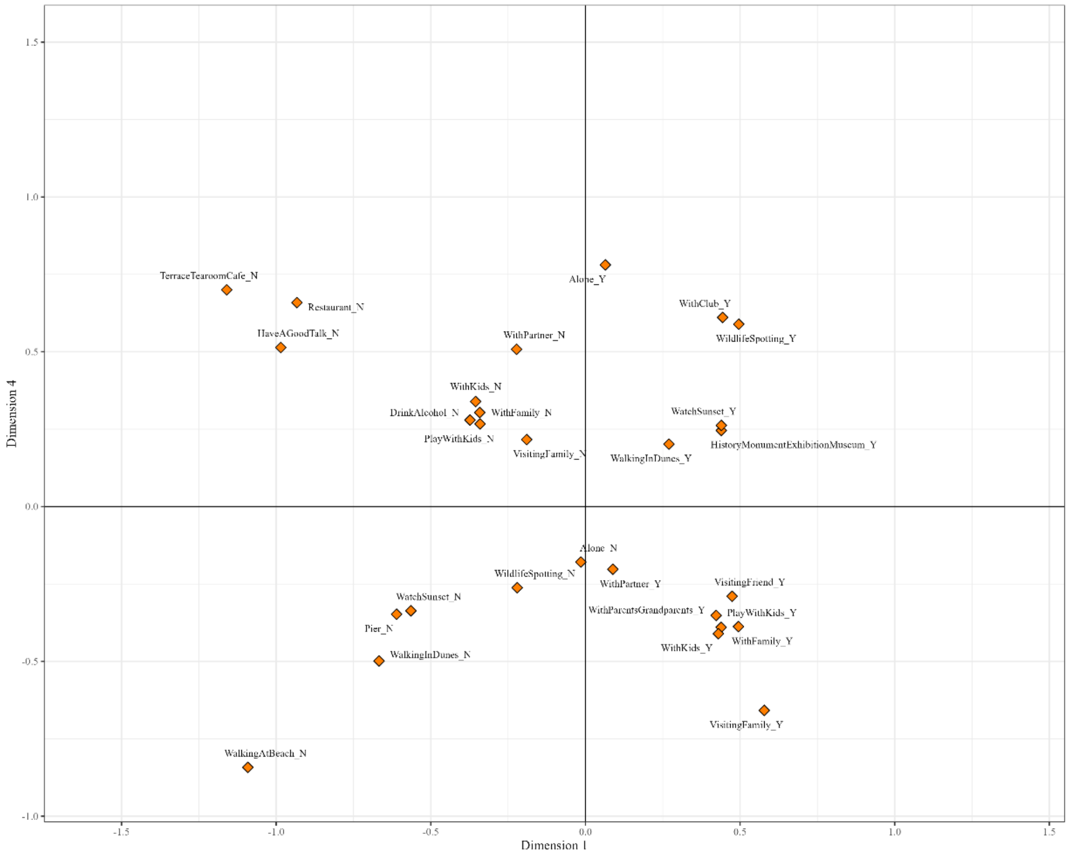

Figure 32: Plane of dimension 1 and 4 with the main categories that contribute above average to dimension 4.

Visiting family or a friend tends to be less associated with positive experiences at the coast. These visits are particularly done by middle-aged full-time workers with a high income and high social-support base (Figure 33). In contrast, exploring the coast alone or with a club is typically done by young adults who live alone, with friends, or with their parents or other family members. These explorers are more likely to be from the hinterland (5-20km from the coast) or have work that involves the coast. They also tend to have a relatively low mental health and low social support base and are very physically active. Explorers tend to solve their problems at the coast and enjoy the sand between their toes, but also tend to feel anxious more often.

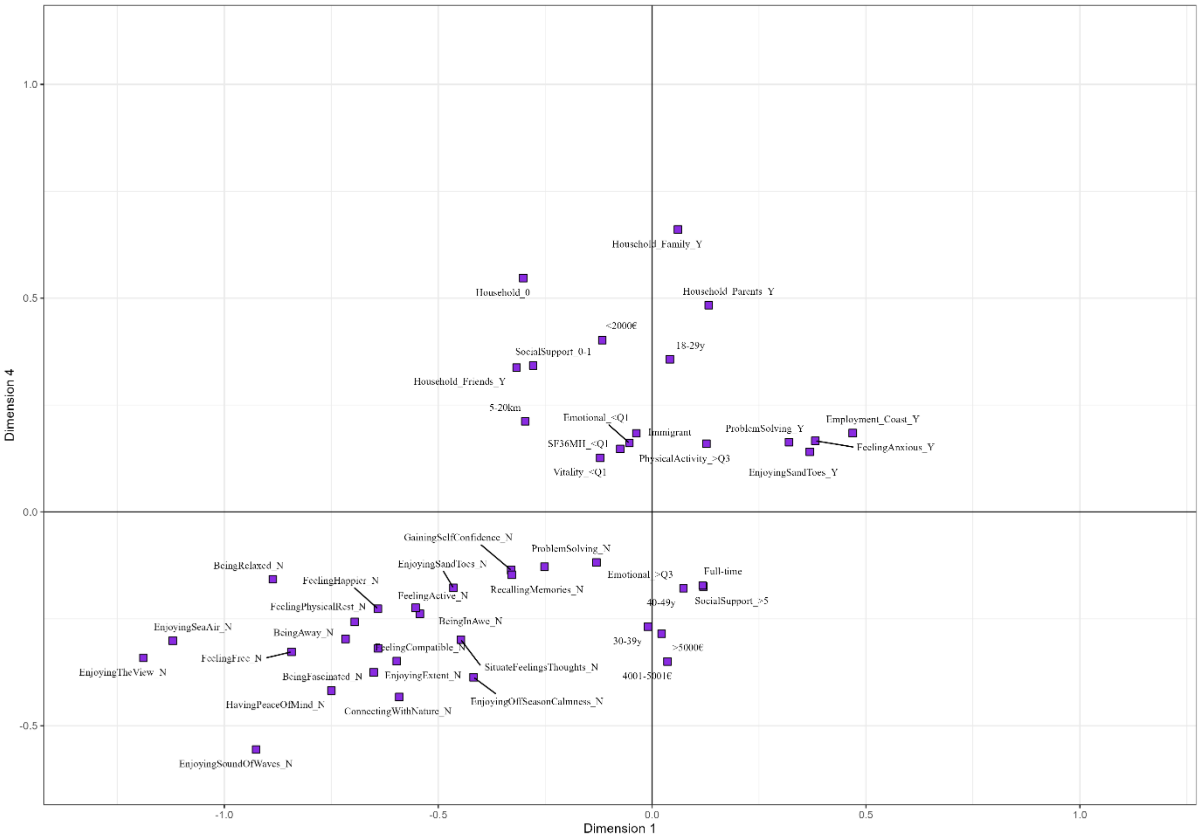

Figure 33: Plane of dimension 1 and 4 with the supplementary categories of which the coordinates on dimension 4 are different from 0 (based on typicality tests) and are above the average of the absolute coordinates on dimension 4.

3.2. Clusters defined (aim 3)

The AHC analysis resulted in five relevant clusters (Figure 34). Each individual was assigned to only one cluster and the five clusters contained all the individuals in the sample, with each cluster more or less holding a fifth of the sample. There was a significant drop in the η^2 when decreasing the number of clusters from six to five (Figure S 42), which would indicate that six clusters should be retained. However, we retained five clusters, because cluster 6 only contained 2.07% of the sample (exploratory analyses show that this cluster harbors the most extreme individuals of cluster 1 along the dimensions). The sample was divided in two major branches: one containing 61.83% of the individuals divided over clusters 1, 2, and 3, and one containing 38.17% of the individuals divided over clusters 4 and 5 (Figure 34, Figure S 43). Within the first and largest branch, clusters two and three were more similar to each other than to cluster 1. The five clusters were interpreted by their location in the planes of dimension 1 and 2 (Figure 35), 1 and 3 (Figure 36), and 1 and 4 (Figure 37) and by the over- and under-representedness of the main and supplementary categories within these clusters (Table S 29). Each cluster was labelled by the coastal leisure activities that the individuals typically exhibit, rather than by their demographic, socio-economic, and health characteristics. Each cluster is further described below, and a summary of the interpretations from the figures (Figure 35, Figure 36, Figure 37) and table (Table S 29) is depicted in Table 15.

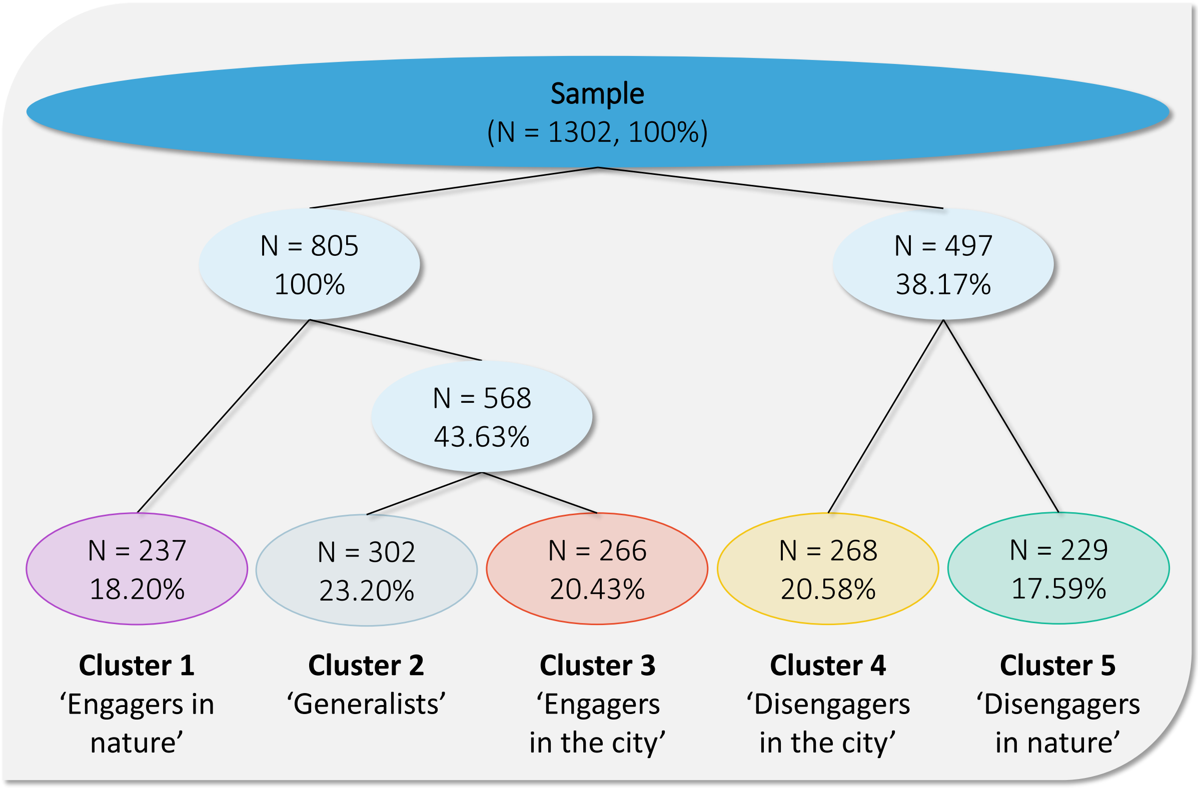

Figure 34: Overview of the five clusters identified by the AHC analysis in this study.

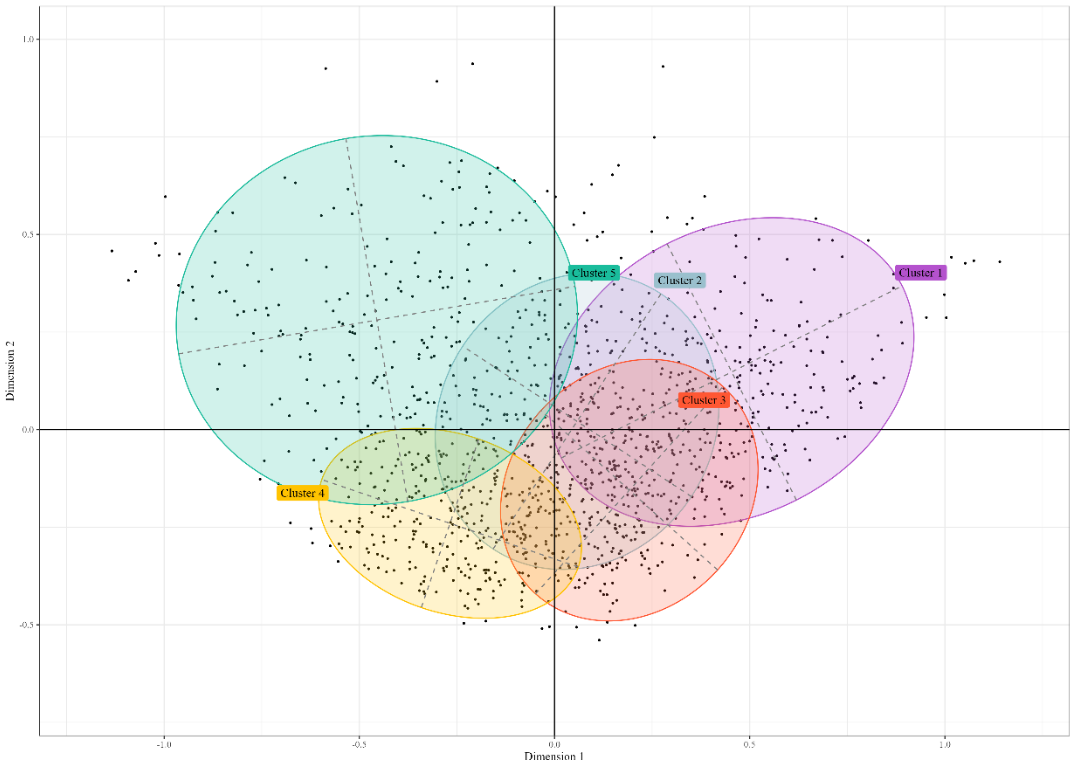

Figure 35: The concentration ellipses of the five clusters identified by the HCA analysis in the plane of dimension 1 and 2.

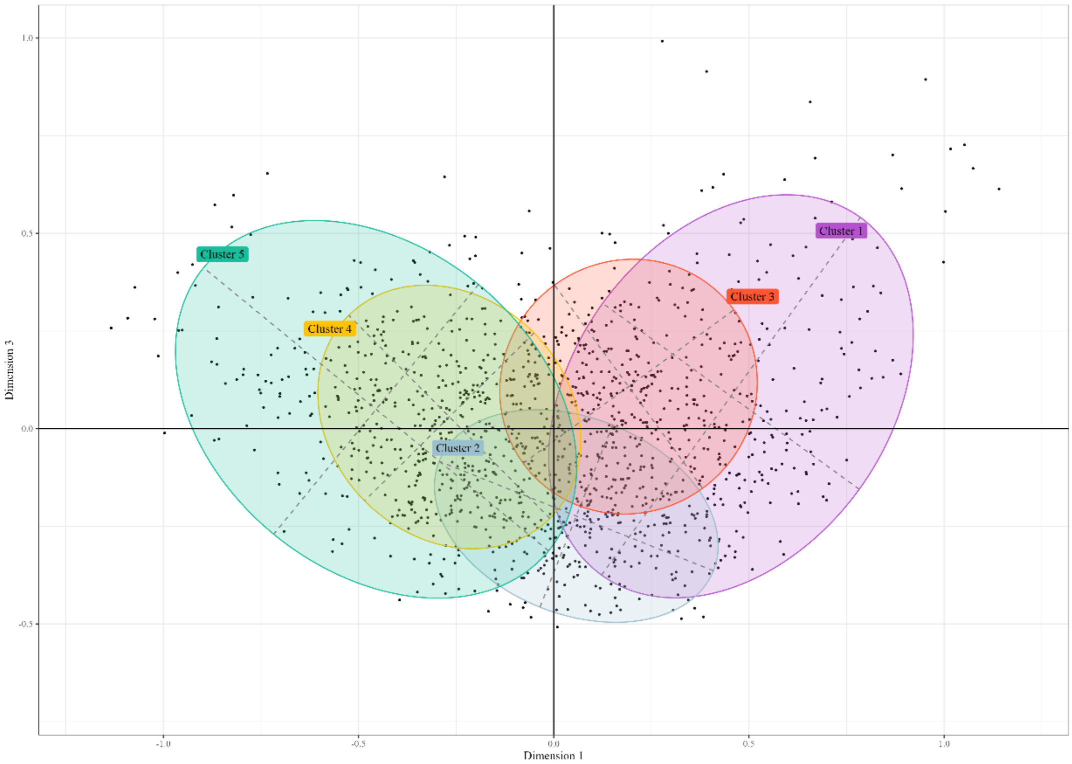

Figure 36: The concentration ellipses of the five clusters identified by the HCA analysis in the plane of dimension 1 and 3.

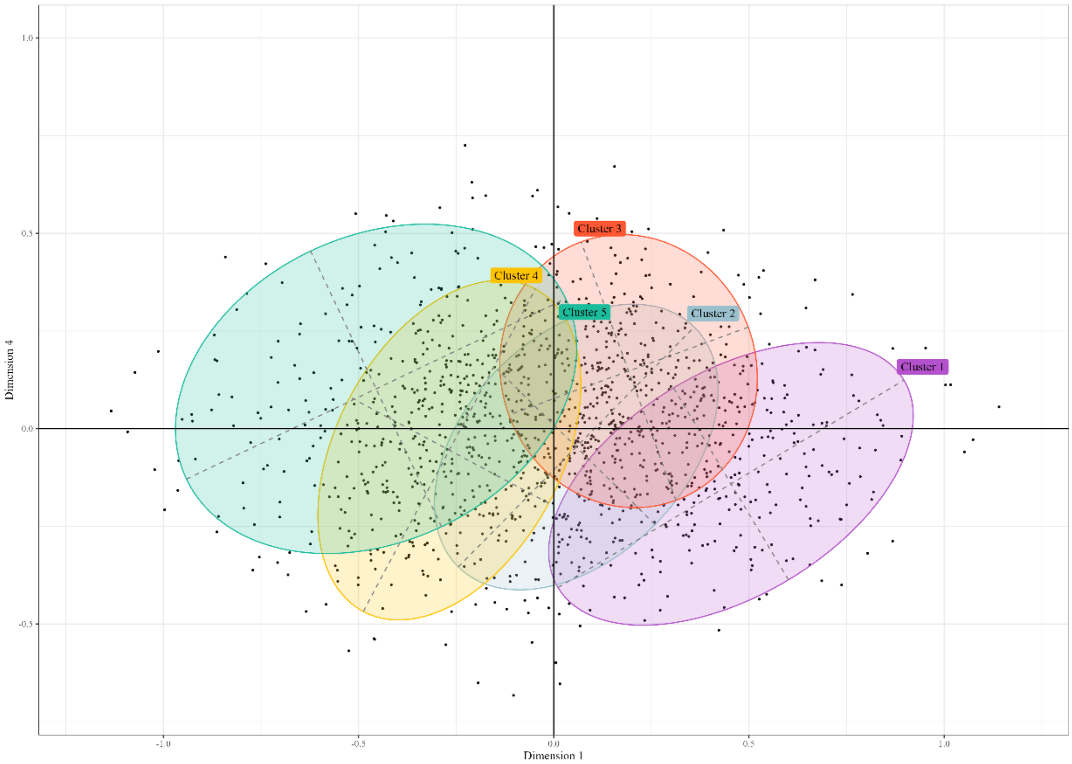

Figure 37: The concentration ellipses of the five clusters identified by the HCA analysis in the plane of dimension 1 and 4.

Table 15: Summary with all essential information about the five clusters identified in this study. Descriptions of the cluster's characteristics are relative to the individuals outside each cluster.

	Cluster 1 'Engagers in nature'	**Cluster 2** 'Generalists'	**Cluster 3** 'Engagers in the city'	**Cluster 4** 'Disengagers in the city'	**Cluster 5** 'Disengagers in nature'
Location along dimension 1	Almost exclusively engaging	Close to the center	Largely engaging	Almost exclusively disengaging	Almost exclusively disengaging
Location along dimension 2	Mostly natural, also urban	Close to the center	Largely urban	Almost exclusively urban	Largely natural
Location along dimension 3	Close to the center	Almost exclusively with partner and kids	Largely with friends and club or alone	Close to the center	Close to the center
Location along dimension 4	Mostly visiting	Close to the center	Largely exploring	Close to the center	Close to the center
Activities	Do most coastal activities Bot physically active and inactive	Activities at the beach, sea, dike Eating out	Do most 'exploring' types of activities, but relatively more likely to often do urban activities	Eating out, drinking alcohol, exploring city Do not often do most other activities	Do not often do most of the activities
Social company	Highly social, including all types of social company (not alone)	With partner and kids Not with friends or club, nor alone	Alone, or with friends or club Not with partner or kids	Less often with social company or alone	Alone Not with social company
Visits	Stay overnight in any season Spent >8 days at coast	No day visits in fall or winter Not spend more than 8 days at the coast per year	Stay overnight Spent >8 days at coast No day visits in summer	Do not stay overnight in summer or spring	Spent one day at the coast Do not stay overnight at the coast
Experiences	Feel bored or anxious All other positive experiences	Enjoy sand between toes Nothing else in particular	Gain most of the positive experiences	Do not gain most of the positive experiences	Do not gain most of the positive experiences
Demography	40-49y Residing at <5km from the coast Owning of a holiday residence at the coast Living together with more than one person, including a partner Having >5 people for social support >5 visits per year as a kid	30-49y Is accompanied by >1 person in the household Do not live with partner	18-29y or >=65y Live alone Female Working part-time	>=65y Not 40-49y Live with 1 person Live with partner	18-29y Live at 5-50 km from the coast West-Flanders Live alone Have little social support (0 or 1 person) Part-time employed
SES	Employed at the coast Actively employed Household income not less than 3000€/month	Highly educated	Household income less than 2000€/month Not actively employed Less likely to be highly educated	Not actively employed Medium educational attainment	Household income less than 2000€/month
Health	Not found to be clearly different	Not different	Physically active (>Q3)	Physically inactive	Low overall mental health Low emotional health Low vitality

3.2.1. Cluster 1: 'Engagers in nature'

The first cluster is located almost exclusively at the engaging side of the first dimension, mostly on the natural side of the second dimension, close to the center of the third dimension, and mostly on the visiting-family-or-a-friend side of the fourth dimension (Figure 35, Figure 36, Figure 37). This cluster represents a group of individuals that is relatively more prone to often do many of the listed activities at the coast and to do so in a highly social context and in mostly natural coastal environments (Table S 29). They are more likely to reside at the coast either by living there, having a holiday residence there, or by doing overnight stays in an accommodation during their holiday, and have reported to have spent relatively a lot of time at the coast when being a kid. This group further has a relatively high socio-economic status (i.e., high social support and medium-to-high income) and is likely to experience many benefits of the coast. However, they are also more likely to feel bored and anxious more often than individuals not belonging to this cluster.

3.2.2. Cluster 2: 'Generalists'

The second cluster is located close to the center of the first, second, and fourth dimension, and almost exclusively at the partner-and-kids side of the third dimension (Figure 35, Figure 36, Figure 37). Their pattern of coastal leisure activities suggest a relative preference for spending time at the most crowded coastal environments (i.e., the beaches and dikes and where one can eat out), mostly in summer, and to do activities with partners and/or kids (Table S 29). They are more likely to be middle-aged and highly educated, and they tend to gain similar experiences as other coastal visitors, except that they are more likely to enjoy the sand between their toes more often.

3.2.3. Cluster 3: 'Engagers in the city'

The third cluster is located largely at the engaging side of the first dimension, the urban-activities side of the second dimension, the alone-with-friends-or-club side of the third dimension, and the exploring side of the fourth dimension (Figure 35, Figure 36, Figure 37). Similarly as the first cluster ('Engagers in nature'), they are relatively often at the coast in the context of their home or overnight stays in an accommodation (Table S 29). However, this group mainly seems to represent either young or older adults that live alone and engage relatively less often in family-related activities at the coast. They are also more likely to visit the coast outside summer and to do more activities in urban coastal environments. They are also relatively physically active throughout their lives.

3.2.4. Cluster 4: 'Disengagers in the city'

The fourth cluster is located almost exclusively at the disengaging side of the first dimension, almost exclusively at the urban-activities side of the second dimension, and close to the centers of the third and fourth dimension (Figure 35, Figure 36, Figure 37). They constitute of a larger share of older, retired, sedentary, adults above the age of 65 that may live with their partner (Table S 29). This profile seems to avoid natural coastal environments and to be drawn towards the city to explore or eat out, and nothing more in particular. Their visit pattern is associated with a lower likelihood of often gaining positive experiences at the coast.

3.2.5. Cluster 5: 'Disengagers in nature'

The fifth cluster is located almost exclusively at the disengaging side of the first dimension, largely at the natural-activities side of the second dimension, close to the center of the third dimension, and close to the center of the exploring side of the fourth dimension (Figure 35, Figure 36, Figure 37). They are more likely to visit the coast alone and to spend time mainly outside the coastal cities' boundaries (Table S 29). They are also more likely to live relatively close to the coast (i.e., 5-50km), and to be socially-isolated individuals who have little social support and/or live alone. Not only are they relatively deprived in terms of social support, they are also more prone to have a low income and to be in very poor health. This group of individuals is likely to not often gain positive experiences at the coast.

4. Discussion

4.1. Main findings

This study aimed to better understand the impact of the coast on human health by disentangling the social structuring of self-reported leisure activities and social company at the Belgian coast in 2022. Bourdieu's distinction theory was adopted and the multivariate analyses MCA and AHC were applied.

Most interestingly, four dimensions were identified that distinguished the leisure activities and social company on the basis of respectively the level of engagement, whether visitors typically go to natural or urban environments, whether visitors are accompanied by partner or kids versus with the friends, the club, or no one, and whether the visit is about strengthening social bonds or about exploring the coast. While interpreting these dimensions, it is important to remind that these dimensions reveal a continuous change from one particularly distinctive set of covarying behaviors to another, with more distinctive and more covariant behaviors at the edges. The categories at one edge of a dimension particularly do not covary well with behaviors at the other edge, and these categories have contributed to forming the dimension most strongly and are thus of primary relevance for structuring the activities and social company.

The first and most explanatory dimension distinguished activities that were performed never, seldom, or sometimes from those that were performed often or always. Therefore, it hints to the level of 'engagement' as being an important structuring factor. At the extremes, it highlights that it is atypical to not eat out at the coast, to not walk along the beach, to rent equipment (e.g., a lounge or a go cart), or to do beach- or watersports. It is quite common in sociological analyses of patterns of participation in cultural leisure activities with MCA that the first axis distinguishes on the basis of the level of engagement, participation, or involvement (Bennett et al., 2010; Roose, 2015; Roose et al., 2014). However, while in those studies the first axis was mainly related to the individuals' cultural capital and socio-economic status, the first axis in this study was not. In this study, the first axis simply seems to be associated with the time that an individual spends at the coast during the year. More specifically, engaging in coastal leisure activities closely covaried with residing at or working with the coast or having stayed in a holiday residence at the coast that is owned or rented, whereas disengagement was associated with visiting the coast only once a year. We focused on respondents that actually stated to have visited the coast in the previous year, so the MCA may have simply revealed that in essence the visit frequency within that year is of primary structuring relevance, and that a higher visit frequency is associated with reporting to perform one or more coastal leisure activities more often. As such, this result also contributes to recent findings about the absence of a role of socio-economic status in determining people's coastal visit frequency (Geiger et al., 2023).

That the stated level of engagement along the first axis is associated with the visit frequency may also be the result of an important contrast between those who are fulfilled in their desire to visit the coast versus those who are not. It is usually hypothesized that the reported frequency of engagement is a relatively good indicator of the actual time spent doing that activity, and the error with which a respondent has evaluated this frequency is usually acknowledged as a limitation. However, a respondent may unconsciously indicate that particular coastal leisure activities are performed rather few times (e.g., never, seldom, or sometimes) purely due to that individual's desire to perform these activities more often (Billiet & Waege, 2009). Alternatively, respondents that report to perform activities often or always may be relatively satisfied in their needs to do these activities. Furthermore, self-reported frequencies may also contain the perceptions of how often other visitors perform these activities, and how much the individual would unconsciously like to be part of that group of visitors that often – or less often – spends time at the coast (Bourdieu, 1984; Weininger, 2010). Interestingly, our results show that individuals who report to engage less often with the coast typically live alone and have little social support. Previous research has shown that people in social isolation are generally more dissatisfied with their lifestyle behaviors (Dedoncker et al., 2021; Mikulincer & Shaver, 2013; Warr et al., 2020). Consequently, the association between social isolation and expressing low frequencies of engagement in coastal leisure activities may have occurred for three reasons: either because coastal leisure activities are really performed less often by people in social isolation; and/or because people in social isolation are more dissatisfied in their desire to do coastal leisure activities; and/or because people in social isolation have an urgency to belong to those individuals who visit the coast more often and who are (perceived to be) more social. In the context of Bourdieu's distinction theory, the last reason would mean that visiting the coast and being more social typically happens by individuals who are perceived to have a higher status, a status that other individuals may set as a target. In the late 18th century, the high-class and privileged individuals were seemingly the first modern humans that seem to have visited the coast for leisure, and their coastal leisure behavior was later adopted by the lower classes (Boterberge et al., 1987; Charlier & Chaineux, 2009). It is plausible that this cultural history is reflected in our results by today's perceptions about the value of coastal visits for an individual's socio-cultural status. Thus, the first dimension may not only distinguish based on the level of engagement and visit frequency, but also by the relative satisfaction in the desire to visit the coast as a display of socially appraised behavior.

The second dimension structured the coastal leisure activities mainly according to whether they happen in natural or urban environments. More specifically, it revealed that there is a contrast between individuals who most often spend time on the beach or in the water and those who most often eat out, stroll on the dike, explore the city, or visit cultural exhibitions. Previous research has shown that both natural and urban environments may offer restorative experiences (Elliott et al., 2023; Othman et al., 2020; Weber & Trojan, 2018), but that spending time in nature is generally more beneficial for health than spending time in urban environments (Triguero-Mas et al., 2017; White et al., 2010). For coastal environments, one previous study showed that students experience natural coastal environments as psychologically restorative and urban coastal environments only as neutral (Hooyberg, Michels, et al., 2022). Crucially, this study adds to this knowledge by showing that there is an important variation between people who favor natural vs. urban environments at the coast. More specifically, our results show that visiting mostly natural – and not urban – environments when at the coast is associated with being accompanied by children, younger age (i.e., below age of 50), living with children and family, being highly educated, having a poorer health, residing in close proximity to the coast (i.e., < 20 km), owning a holiday residence at the coast, or having work related to the coast. In contrast, visiting mostly urban – and not natural – environments when at the coast is associated with not being accompanied by children, older age, living alone or just with the partner, having a low education, having a better health, or having stayed one or more nights at the coast outside the summer season. These patterns suggest that the visitor's demographic, socio-economic, and health background may be important for determining the environment that is visited at the coast. This dimension also demonstrates that a person who is used to doing urban-based activities would typically not do nature-based activities, and vice versa. With the coast being put forward as a potentially cost-effective health-promoting therapy for people with a poor mental health (e.g., Britton et al., 2018; Coventry et al., 2021; White et al., 2018), these results suggest that getting urban dwellers at the coast to visit natural coastal environments may be a difficult challenge and that this may contradict with a person's habitus and social positioning.

The third dimension highlighted that, next to the level of engagement and the environment, also the social context of the visit is important for structuring coastal leisure activities. More specifically, middle-aged parents with kids who visit the coast with their family are opposed to either young or older visitors without kids and who visit the coast alone, with friends, or with a club. Previous research has illustrated that the coast and other natural environments are important for strengthening social bonds with family and friends, and that this is one of the main mechanisms by which health can be enhanced (Ashbullby et al., 2013; S. L. Bell et al., 2015; Hartig et al., 2014; White et al., 2020). Our third dimension highlights that there is an important variation within the types of social company, and that those who visit the coast within the family-context are likely to visit the coast in a different way than those who do not. In the most extreme cases, visitors with friends typically do not walk at the beach, but rather go to shows or festivals, rent a lounge, or do water- or beach sports, whereas visitors with kids do not seem to prefer particular activities besides playing with those kids and searching shells on the beach. It also shows that it would be highly atypical if an individual would visit the coast with both family members and friends. Thus, the third axis shows that the type of social company modulates the activities performed at the coast, and that there are particular coastal leisure activities that typically happen either with family, or with friends, and usually not with both together.

The fourth dimension revealed an opposition between individuals oriented towards exploring the coast and those oriented towards spending quality-time with family. More specifically, this dimension shows that it is very atypical to often go wildlife spotting or visiting cultural exhibitions, or in contrast, to mostly spend time visiting family or friends and not often go out walking at the beach or dunes. This pattern suggests that the different activities that these individuals do may be a display of whether they give more value to socially-induced or environmentally-induced experiences. Exploring-like behaviors along this dimension seem to be particularly incompatible with occasions in which their attention might be distracted from the environment. These distractions may be of social nature, such as being joined by family members or friends and having a good talk, or of other nature, such as eating out or drinking alcohol. In contrast, the social-oriented visitors seem to be rather negligent towards the coastal environment. These opposing preferences seem to be reflected in the individual's demography and socio-economic status. More specifically, preference for social activities covaries with being a middle-aged full-time worker with a high social-support base and high income, whereas preference for exploring activities with being a young adult who lives alone, with friends, or parents. It is not clear whether the preference for performing either social versus exploring behavior at the coast is either a display of what they normally tend to give preference to in everyday life, or a compensation of experiences that are typically not gained in everyday life and leisure time at the coast provides an opportunity to fill those needs. In any case, this axis demonstrates that people can distinguish themselves at the coast by either devoting attention to experiencing the environment or to strengthening social bonds.

In the last part of this study, five clusters of individuals with a relatively distinct coastal visit and individual profile were identified. These clusters revealed on average cross-dimensional (dis-) similarities among individuals and give an idea about what types of visitor profiles can generally be distinguished at the Belgian coast, above and beyond what coastal visitors generally do. The largest cluster contains the 'generalists' (cluster 2, 23.20%). They have not really a preference to engage or to disengage, or to favor natural or urban environments. This cluster hints to a group that holds relatively more middle-aged parents who tend to do activities with their children, and who visit the coast relatively often and spend most time at the more popular and crowded locations at the coast, i.e., beaches, dikes, and places to eat. They also prefer to visit the coast during high-season more than individuals not belonging to this cluster, potentially because the favorable weather conditions in summer allow them to enjoy the coast more fully. These generalists are relatively similar to cluster 3 ('engagers in the city', 20.43%) that contains individuals who also visit the coast relatively often but that are more likely to be either younger or older. This group relatively prefers the urban environments at the coast and to visit the coast without a partner or kids and less often in summer. Perhaps, these individuals avoid the crowded coasts in summer, because they are more likely to live alone and to avoid the confrontation of seeing many socially-engaging visitors in summer. Their preference for urban environments can be attributed to the less-favorable weather during off-season for nature-based activities, and because they are less constrained to offer their children a pleasant experience (e.g., children prefer nice weather and beaches). Both of these clusters differ from a third, smaller cluster (cluster 1, 'engagers in nature', 18.20%) who more often engage in natural activities at the coast, such as beach- or water sports, and relatively more often in a social context. Their socio-demographic profile suggests a highly social group of higher social class that can afford to spent many days at the coast throughout the year and to engage in both cheap-option (e.g., spending time at the beach) and more expensive (e.g., going to a restaurant) coastal leisure activities. They seem to have the coast embedded in their cultural lifestyle: they are more likely to either live by the coast (< 5 km), have a holiday residence at the coast, and have visited the coast relatively often as a kid. As opposed to these first three clusters, there are two clusters who constitute of retired (cluster 4) and young (cluster 5) individuals who disengage at respectively urban and natural environments at the coast. Individuals in cluster 4 ('disengagers in the city', 20.58%) are typically retired, physically inactive, and potentially disabled people who are more likely to dwell in the city, eat out, and nothing else in particular. They have generally no differential preference for the type of social company during their visits. These visitors are more likely to live with their partner and to not stay at the coast during spring or summer. Lastly, individuals in the relatively small cluster 5 ('disengagers in nature', 17.59%) are more likely to be young, infrequent visitors of the coast. They tend to not do longer stays at the coast and to only spent one day at the coast during the year. When they do visit the coast, they are relatively more likely to come alone. This solitariness behavior matches with their socio-demographic profile: they are also more likely to live alone, have little social support, are part-time employed, and have a low mental health. Thus, the five profiles of coastal visitors identified in this study tend to match the socio-demographic and health characteristics of these visitors. These profiles seem to be particularly linked to the age and household situation and the level of social isolation, which provides additional leverage to further investigate the social context as a relevant modulator for one's coastal visit behavior.

The results of this study also allow to deduce relevant insights about in which situations positive experiences are most likely to happen. Previous literature found that coastal visitors experience many different emotions and mood states when at the coast (S. L. Bell et al., 2015; Severin et al., 2022), and that natural environments (at the coast) effectively provide psychophysiological stress-reduction and attention restoration (Hooyberg, Michels, et al., 2022, 2023). In this study, twenty-seven experiences were included in the analyses, of which two were negatively-valenced (i.e., feeling anxious and being bored) and the remaining positively. The positively-valenced experiences referred to prerequisites for attention restoration defined by attention restoration theory (e.g., fascination, being away; Hartig et al., 1997), mental and physical symptoms of stress-reduction and coping (e.g., being relaxed, having peace of mind, feeling physical rest, situate feelings and thoughts), sensational experiences (e.g., enjoying the sea air, enjoying the sound of the waves), and situational experiences (e.g., enjoying summer crowding, enjoying off-season calmness), among others. All of these experiences are in one way or another relevant for understanding how the coast impacts human health. The previous chapter in dissertation described how often the sample reported to have gained these experiences (Figure 20 panel g). This study contributes to the current knowledge by showing how the occurrence of these experiences is linked to the characteristics of the visits and visitors. Most importantly, it shows that positive experiences happen less often for when there is disengagement in natural environments at the coast (top-left quadrant in plane of dimensions 1-2), when the coast is not visited in a family context (top of dimension 3), and when the social company during the visit draws attention away from the environment (bottom of dimension 4). These results are in line with the literature that shows that having an active interaction with the coast is a prerequisite for any effects of the environment to be effectuated on the individual (Elliott et al., 2023; Wyles et al., 2019). As a result, the individuals in clusters 4 and 5, i.e., the retired urban disengagers and the solitary young adults who disengage in nature are likely to miss out on the benefits of the coast.

4.2. Strengths and limitations

This study analyzed patterns in the visits to the Belgian coast by Flemish inhabitants in the year 2022. As such, we did a momentary assessment and did not consider historical trends in these behaviors. It is known that lifestyle behaviors, including available leisure time and the time devoted to visiting the coast, may vary according to the geographical region and economic, political, social, and other trends in society (Boterberge et al., 1987; Charlier & Chaineux, 2009; Wilczyńska et al., 2023). Therefore, making conclusions about similar structuring patterns in other regions or time periods cannot be made. In prospect, the results of this study may become outdated in the future when significant changes occur in the Flemish society and in people's lifestyle choices and priorities. Additionally, we also neglected the characteristics of Flemish inhabitants that reported to not having visited the coast in 2022, and an investigation of their attitude towards visiting the coast might reveal additional interesting patterns. Nevertheless, by focusing on a well-defined time period, region, and sample, we were able to find that coastal leisure activities vary according to the level of engagement (or visit frequency, or desire to visit the coast), type of preferred environment, social company, and a social vs. exploring attitude. All of these factors seem to be of value for human beings irrespective of cultural or geographical origin (Hurly & Walker, 2019; Shores et al., 2007; Ulrich, 1993).

In our data pre-processing, we neglected the continuous character of the self-reported frequencies of coastal leisure activities, social company, and experiences, and dichotomized them as having occurred never, seldom, or sometimes versus often or always. Considering coastal visit behaviors as continuous has proven to be useful from an epidemiological perspective (Elliott et al., 2020). However, that is less relevant from a sociological perspective. More specifically, according to Bourdieu's social distinction theory, people have consciously or unconsciously either a preference or aversion towards performing activities that are sensed to be conducive to one's social status (Bourdieu, 1984; Hjellbrekke, 2018; Roose et al., 2014). Moreover, dichotomizing self-reported frequencies – like we did in this study – has proven to enable a more efficient analysis and clearer results in previous socio-behaviorally oriented studies (Bennett et al., 2010; Roose et al., 2014). Related to this is that a particular strength of this study is the aggregation of a multitude of visit- and visitor-specific variables in one set of analyses. By combining visitors' activities, social company, and experiences at the coast to their demographic, socio-economic, and health characteristics, we revealed that many of these variables are entangled with each other and that looking at them simultaneously allowed to gain insights of both epidemiological and sociological relevance. It seems that previous blue-space oriented research has not often incorporated such a sociological view previously (White et al., 2020). Thus, although trade-offs had to be made, our sociologically-inspired analyses on openly available data of self-reported coastal visits allowed us to bring a new wind to the research about the effects of the coast on human health.

4.3. Future research

Previous studies that targeted to investigate the effects of the coast on human health have generally focused on how a specific group of individuals reacts to a specific environment while standardizing what the participant may do or not do in the environment (e.g., walking, roaming free) (Hooyberg, Michels, et al., 2022, 2023; Triguero-Mas et al., 2017; Vert et al., 2020). Nonetheless, this study and previous studies have demonstrated that the type of activities may vary considerably depending on the individual (Boyd et al., 2018; Dean et al., 2022; Elliott et al., 2018; Wilczyńska et al., 2023), and that the level of physical activity (Britton et al., 2023; White et al., 2015) and the social company (S. L. Bell et al., 2015; Staats & Hartig, 2004) may drastically enhance or deteriorate the effects (Elliott et al., 2023). Therefore, the field of research would benefit from new observational and experimental studies that evaluate how different visitor profiles experience the coast differently on both psychological and physiological metrics. These studies should not only assess why an individual exhibits particular behaviors according to its social status (Bourdieu, 1984), but also encompass motivational, practical, and expectational factors. For this, the reasoned action approach (Ajzen, 1991; Ajzen & Driver, 1992; Conner et al., 2017; McEachan et al., 2016), the expectancy-value principle (Eccles & Wigfield, 2020; Van Der Pligt & De Vries, 1998), leisure constraints theory (D. W. Crawford et al., 1991; Shores et al., 2007), and health belief model (Carpenter, 2010; Rosenstock, 2005) seem relevant. As a result, researchers would be able to compare studies that used different social groups and that seemingly resulted in conflicting effects more easily, and to be able to gain a more complete understanding about the mechanisms of exposure and effects. That being said, future research should also aim to extend the findings to other regions with both relatively similar (e.g., Netherlands) and dissimilar (e.g., outside Europe) cultural and historical backgrounds, and to apply the gained knowledge within the literature about the ocean and human health, nature and health, and blue therapies.

5. Conclusion

This study aimed to unravel the variability in leisure activities undertaken at the coast, while considering the environmental, physical, and social context in which they occur, and to investigate how these activities covary with the season and type of coastal visit (i.e., day visits vs. longer stays), the experiences gained, and the demographic, socio-economic, and health characteristics of the individual (Figure 24). To do so, Bourdieu's social distinction theory (Bourdieu, 1984) was adopted and the sociology-inspired analyses specific MCA and AHC were implemented (Hjellbrekke, 2018). As a result, four structuring dimensions were identified along which five clusters of individuals could be distinguished. The first dimension distinguished on the basis of the level of 'engagement', visit frequency, or fulfillment in the desire to visit the coast, the second dimension according to whether mainly natural vs. urban activities are performed, the third dimension based on whether or not the visit happens in the context of family or not, and the fourth dimensions according to whether value is given to exploring the environment or strengthening social interactions. Based on the individuals' locations along these dimensions, we could distinguish 'generalists' (23.2% of the sample), 'engagers in nature' (18.2% of the sample), 'engagers in the city' (20.4% of the sample), 'disengagers in nature' (17.6% of the sample), and 'disengagers in the city' (20.6% of the sample). As such, our results provide a map to disentangling the (social) structuring of coastal leisure activities and social company at the coast. We discussed how each of these dimensions and clusters contribute to the existing literature and to understanding the effects of the coast on human health. Furthermore, the results strengthen the importance of taking a multidisciplinary perspective, and that especially the social context of coastal leisure activities is crucial for modulating both the activities performed and the experiences gained. Future research should target investigations within and between these clusters and across geo-cultural regions to confirm and better understand relationships between the use of the different environments and provisions at the coast and the health effects gained.


EHBO HULPPOST
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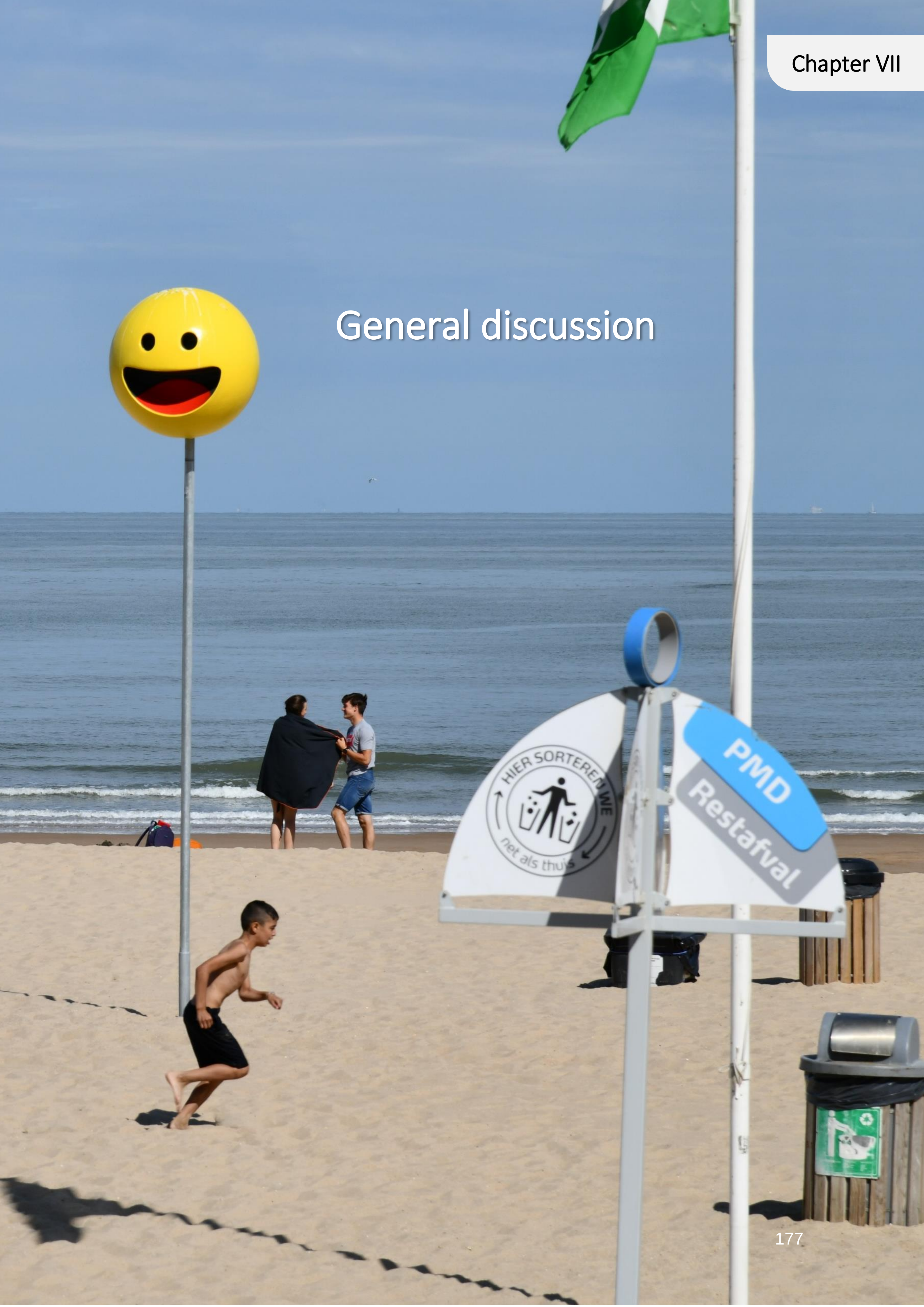
General discussion



1. Overview

This doctoral research aimed to increase the evidence and our understanding about the effects of exposure to the coast on human health as outlined by the conceptual framework of White et al. (2020). Four empirical studies and a data descriptor were completed (Table 16). Chapter II describes an epidemiological study about the effects of living nearer the coast on general health and the mediating effects of four hypothesized mechanisms; Chapter III describes a picture-rating study in the lab to evaluate the effects of different coastal environments on psychological restoration and the mediating influence of environmental components; Chapter IV describes a virtual-reality exposure experiment that compared the psycho-physiological effects of beaches vs. inland green and urban spaces, while considering the respondents' initial stress level; Chapter V is a data descriptor about the coastal visit and individual characteristics of a sample of citizens in Flanders; and Chapter VI describes observational patterning analyses on the coastal visit and individual characteristics gathered in the previous chapter (Table 16).

This discussion outlines how each chapter within this dissertation is at the forefront of understanding the coastal experience and how each chapter contributes to providing evidence and gaining understanding about the effects of the coast on human health. More specifically, it outlines how they contribute to answering the overarching research questions A and B.1 defined by the SOPHIE SRA (H2020 SOPHIE Consortium, 2020); and to understanding the effects of the coast on human health in the framework of White et al. (2020; Figure 38; see also Figure 4 in the Introduction). However, before discussing the scientific yield of each chapter, important notes are made about the methodological choices and the external validity of the studies. With the adopted methods in mind, the discussion further highlights that fundamental knowledge gaps remain for dose-response relationships and about the influence of the coast for bio-psycho-social resilience. It also describes what future research is necessary to lead to innovative societal applications in the near or more distant future. More specifically, it describes how the effects of exposure to the coast on human health can benefit health care, how the economic consequences of exposure to the coast can be valued, and how a more sustainable interaction with the ocean can be enabled. Lastly, it proposes the way forward for this research topic by adopting the 'specific approach to health': the boundaries of the topic are discussed, conceptual pitfalls of White et al.' (2020) framework are discussed, and science-policy linkages are illustrated.

Table 16: Overview of the five central chapters in this dissertation.

	Chapter II	Chapter III	Chapter IV	Chapter V	Chapter VI
Aims	• Determine the relationship between residential proximity to the coast and self-reported general health • Reveal the mediating role of four hypothesized mechanisms	• Quantify the inter- and intra-environment variation in psychological restoration • Quantify the mediating effect of naturally varying doses of natural and urban components and people	• Quantify how diverse psychological and physiological parameters of stress respond differently to beaches vs. outdoor green and urban environments • Quantify the moderating effect of the level of stress in the past week	• Develop and describe a dataset with information about residential proximity to the coast, the frequency and characteristics of coastal visits, the resulting mental and physical experiences, and the demographic, socio-economic, and health characteristics	• Structure coastal leisure activities and types of social company • Reveal covariations with the season, frequency, and type of coastal visits, experiences, and demographic, socio-economic, and health characteristics • Identify and describe clusters of individuals with similar leisure activity profiles
Data origin	Health Interview Survey (Sciensano, 1997-2013)	Picture-rating study	Virtual-reality experiment	Survey in 2023 about 2022	Chapter V
Population	Belgian adults (N = 60,939)	Students (N = 102, 18-30y, 83% female)	Adults (N = 164, 18-65y, 68% female)	Flemish adults (N = 1939)	Coastal visitors in 2022 (N = 1302)
Conceptual exposure	• Residential proximity to the coast	• 10 coastal environments • 5 beach environments • Environmental components	• Beaches • Inland green space • Inland urban space	• Visits	Structuring variables • Activities performed • Social company
Actual exposure	• Modelled fastest travel distance from the center of the municipality of residence	• 52 pictures, shown for 8 seconds each • Surface area of environmental components	• Eight two-minute 360° virtual reality videos with sound	• Recalled visits	Structuring variables • Recalled activities performed • Recalled social company
Conceptual outcome(s)	• General health	• Psychological restoration	Psychological • Stress • Positive mood • Negative mood • Psychological restoration	Visit characteristics • Frequency • Activities • Social company • Experiences	Latent structuring variables

			Physiological arousal • Cardiovascular • Parasympathetic • Sympathetic • Somatic • Breathing	• Reasons for not visiting the coast more often	
Actual outcome(s)	• Self-reported momentary general health (rated 1-5)	• 'Psychological restorativeness' implicitly induces recalling previous psychological restoration and translating to a future hypothetical scenario (rated 0-10)	Psychological • Self-reported stress level (rated 0-10) • Positive mood (rated 0-4) • Negative mood (rated 0-4) • Psychological restorativeness (rated 0-10) Physiological arousal • Heart rate and blood pressure • High-frequency heart rate variability • Skin conductance response • Muscle tone • Breathing rate	Recalled visit characteristics • Recalled frequency • Recalled activities • Recalled social company • Recalled experiences • Recalled reasons for not visiting the coast more often	Dimensions Clusters
Mediators/ Moderators	Mediators • Self-reported mental stress (GHQ-12) • Self-reported physical activity (IPAQ) • Appreciation of social interactions • Modelled PM_{10} concentrations	Mediators • Surface area of diverse natural and environmental components and people on the pictures	Moderator • Self-reported stress level of the past week (DASS21-Stress)	Individual characteristics • Self-reported demography • Self-reported proxies for socio-economic status • Self-reported general and mental (SF36MH) health state	Supplementary variables • Season, frequency, and type of coastal visits • Experiences • Demography • Socio-economic status • Health state
Results	• Those living <5 km from the coast report a better general	• 30% higher restorativeness in natural environments	• VR increases physiological arousal	• Data descriptor	Four structuring dimensions

	health than those living inland • None of the hypothesized mechanisms mediate this relationship	compared to neutral urban environments • Benefits from sky, vegetation, natural underground, breakwaters • Harm from urbanization	• Beaches benefit all psychological outcomes, cause lower breathing rate (compared to urban) and lower SNS activity (compared to green) • Beaches benefit individuals with moderate levels of stress in the past week more than green environments		• Engagement • Naturalness • Social company • Purpose Five visitor profiles • 'Generalists' • 'Engagers in nature' • 'Engagers in the city' • 'Disengagers in nature' • 'Disengagers in the city'
Recommendations	• Further investigate the effects of the coast on human health • Further investigate the mechanisms	• Preserve coastal nature • Consider naturalness and spatial heterogeneity when assessing psychological restorativeness at the coast	• Investigate psycho-physiological mechanisms in relation to the state mental health	• Make coastal tourism data openly available • Analyze the social structuring of coastal visits • Analyze 'coastal epidemiology and accessibility', 'health and psycho-physical experiences', 'social relations', and 'issues of time, season, and weather'	• Consider activities and social differences when evaluating effects of the coast on human health • Merge epidemiological with sociological perspectives

2. Methodological considerations

This field of research still contains many knowledge gaps to be resolved, and studies that used real-world coastal exposures have demonstrated that more controlled study designs are required to gain a better understanding and more valid evidence about the effects of exposure to the coast on human health (Triguero-Mas et al., 2017; Vert et al., 2020). Therefore, this dissertation took a step back by carefully making the necessary methodological choices in favor of increasing a better understanding of the influential environmental, psycho-physiological, and sociological effects, rather than providing real hard evidence about the effects of really being at the coast on long-term human health. The adopted methods and used samples fit within the rationale of this dissertation that was to gradually build up the complexity.

Each study in this dissertation used a proxy for the coastal exposure (e.g., residential proximity, pictures, virtual reality, recalled visits) and specific proxies for the conceptualized health outcomes (e.g., self-reports, physiological biomarkers, recalled experiences), and no study in this dissertation has assessed the effects of being really at the coast on objective health outcomes (e.g., health care use, morbidity, mortality) directly (Table 16). Undeniably, this has had an impact on the exposure accuracy and the ecological validity of each included study. For example, in Chapter II and Chapter V, the use of the municipality centers as proxy for the individuals' residential locations is not as accurate as when the actual addresses of the respondents would have been used, and the use of travel time to the coast as a measure for the residential proximity probably does not entirely match with the respondents' real distance to the coast. Furthermore, the used simulations for exposure to outdoor environments have gained popularity in the last decades, because they offer the ability to carefully standardize the exposure and to objectively quantify the features of the exposure (Browning et al., 2021). However, simulated nature cannot bring about instorative and mitigative effects and has also shown to be ineffective for improving positive mood, because it limits a direct interaction with the real environment and only a part of the sensory experience is provided (Browning, Mimnaugh, et al., 2020). Nevertheless, this was less of an issue for this doctoral research, because the main focus was on the restorative effects (especially in Chapter III and Chapter IV). The used proxies for health have been known to be associated well with objective health outcomes, and they allow to acquire data much faster than when objective health outcomes would need to be measured (Idler & Benyamini, 1997; Krijger et al., 2014; Lorem et al., 2020; Wu et al., 2013). Taken together, the use of proxies for the exposures and the conceptual health effects in this dissertation does not seem to present a big issue for the ecological validity of the acquired results.

The validity of the used samples for the targeted populations also requires a careful evaluation. Two of the four data sources used relatively representative samples of the targeted populations: the data from Chapter II originated from a large, random cross-sectional, multi-staged, multi-clustered, and stratified sample of the Belgian population (N = 60,939, 1997-2013) and the data from Chapter V and Chapter VI originated from a quota sample of an access panel of Flemish citizens (N = 1939). The population validity of the study in Chapter III is the lowest, because it used a convenience sample comprising of largely female students (N = 102, 18-30y, 83% female). The sample recruited for Chapter IV had a better age and sex distribution (18-65y, mean age = 34y, SD = 13, 68% female), but was still a convenience sample. Overall, the samples used were deemed appropriate for revealing the envisioned relationships between the exposure and the effects, but the convenience samples in Chapter III and IV require caution when upscaling the results to the wider population.

3. Scientific contributions

3.1. Scientific yield of Chapter II

Before the start of the first study described in Chapter II, there were only indications from England and Ireland that living nearer to the coast would benefit health (Brereton et al., 2008; Wheeler et al., 2012; White, Alcock, et al., 2013). It was also unknown if the effects are everywhere the same at the coast (e.g., if the naturalness of the environment plays a role at the coast, if there is a dose effect water; Neilson et al., 2017, 2016; Nguyen et al., 2018; White et al., 2010), and there was hardly evidence about the effects of the coast on psychological and physiological outcomes (Triguero-Mas et al., 2017). Therefore, as an initial large-scale exploration for Belgium, the first study in this dissertation investigated the effects of living nearer the Belgian coast on self-reported general health (Chapter II; Figure 38). In line with expectations, and controlling for many individual (e.g., age, sex, socio-economic status) and environmental (e.g., green and blue space coverage in the neighborhood) covariates, this study revealed that coastal residents living closer than 5 km from the coast report a better general health than their inland counterparts. As such, it expanded the geographical scope of evidence compared to previous research in other countries (Brereton et al., 2008; Wheeler et al., 2012; White, Alcock, et al., 2013), and it justified exploring the benefits of the coast further.

The literature at the start of the first study described in Chapter II also proposed four mechanisms to be likely for explaining the relationship between nature and health (Hartig et al., 2014), and these mechanisms had only been investigated by looking at them separately and rarely in a coastal context. The study described in Chapter II assessed the four mediation effects described in Hartig et al. (2014) simultaneously and on a country-wide scale. Note that the framework depicting the restoration, instoration, and mitigation pathways proposed by White et al. (2020) was not published at the time when the research questions for the study in Chapter II were being drafted, and investigating them with epidemiological data would have been conceptually difficult anyway (e.g., indexes for 'an instoration effect' do not exist). In any case the four hypothesized mechanisms described in Hartig et al. (2014) are overlapping with the restoration, instoration, and mitigation mechanisms described by White et al. (2020). The study revealed that Belgian coastal residents on average do not perform more physical activity, do not appreciate their social interactions more, and do not have less mental distress compared to inland residents. The study revealed that the air quality (i.e., PM_{10} concentrations) was better at the coast, but this did not explain the better self-reported general health of the coastal residents in Belgium. For a couple of years, it remained a mystery about what the underlying reason would be that coastal residents do feel healthier, but that none of the four hypothesized mechanisms could explain these effects. The solution to this mystery was recently discovered by cross-country analyses on European, American, Asian, and Australian datasets, including data from Belgium. More specifically, a similar analysis as in Chapter II largely replicated our findings: coastal residents report a better general health, but do not report to exhibit higher levels of physical activity and social interactions (Elliott et al., 2023).

Note that coastal residents did report to be in better mental health (Elliott et al., 2023). However, the same datasets also revealed that living closer to the coast results in a higher visit frequency, and that the number of actual visits accounts for more frequent physical activity and social contacts and a better mental health (air quality – NO_2 concentrations – were not directly related to the frequency of coastal visits; Elliott et al., 2023). These data further highlight that the associations were much stronger for proximity and visits to the coast than to green spaces and freshwater blue spaces (Elliott et al., 2023). Thus, the study described in Chapter II justified exploring the benefits of the coast further in Belgium, and more recent cross-country studies demonstrate that the four mechanistic pathways do apply when the coastal visit frequency is accounted for (Elliott et al., 2023). As a last note, it should be mentioned that the basic concept of such mediation analyses contradicts with the specific approach to health. This is further discussed in the Section 5 (third paragraph) of this chapter.

3.1. Scientific yield of Chapter III

Upon seeing the results of the first study described in Chapter II, the idea arose that the absence of mediation effects of the four hypothesized mechanisms had something to do with the spatial heterogeneity at the coast. More specifically, the Belgian coast is characterized by many different types of environments that seem to differ in the level of naturalness. The nature-and-health literature had proposed that the level of naturalness is key for determining the magnitude of health benefits (Kabisch et al., 2021; Marselle et al., 2015; Ode Sang et al., 2016; Van den Berg et al., 2014). Coastal areas were generally considered, or at least treated as, homogenous and largely natural blue spaces, and epidemiological or experimental designs had not considered that coastal environments are often highly heterogeneous (S. L. Bell et al., 2015; Elliott et al., 2023; Geiger et al., 2023; Jellard & Bell, 2021; Triguero-Mas et al., 2017; Vert et al., 2020; Wheeler et al., 2012). Nevertheless, many previous studies suggested that the dose of the physical components and people in the environment potentially co-determine the level of psychological restoration, despite some remaining mixed findings (e.g., about the dose-effect of vegetation and of water; Collado et al., 2017; Gascon et al., 2015; Georgiou et al., 2021; Jiang et al., 2016, 2015, 2014; Karmanov and Hamel, 2008; Labib et al., 2020; Lindal and Hartig, 2013; Maas et al., 2009; Mears et al., 2019; Neale et al., 2021; Neilson et al., 2020, 2017, 2016; Nguyen et al., 2018; Nordh et al., 2009; Staats and Hartig, 2004; Van den Berg et al., 2014; White et al., 2017a, 2010). Therefore, under the assumption that most coastal residents would reside in the cities and urban environments at the coast, it was hypothesized that natural environments at the coast would be more beneficial than urban environments at the coast, and that the residential situation and leisure time of coastal residents would be enough to benefit general health, but not the four hypothesized mechanisms. To test these environmental effects at the coast, the study described in Chapter III investigated the variation in the psychological restoration between ten coastal environments (i.e., testing inter-environment variation) and between five sub-environments at the beach (i.e., testing intra-environment variation). The study also raised concerns about the validity of the results. More specifically, the participants were asked to envision themselves in the coastal environments depicted on the pictures and to rate how much those environments would provide them with restoration in a hypothetical scenario (Hartig, 2011). Furthermore, it should be noted that the picture-ratings in Chapter III were done by students (18-30y, 83% female) and do not allow to translate these effects to the wider population at the coast or in inland regions. Nevertheless, the study described in Chapter III uncovered that the psychological restoration follows the level of naturalness at the coast, both between distinct environments (e.g., beaches vs. dikes) and within the beach (e.g., at the shoreline vs. between beach cabins at the beach). The study also demonstrated that, at the Belgian coast, the likelihood for psychological restoration to occur is enhanced by the dose of vegetation, sky, and natural undergrounds, and not water. The applied rating scale (i.e., adapted perceived restorativeness scale) informed that these effects occurred at both an emotional and stress-reducing level and at the cognitive level. As such, the results of this study confirmed that there is spatial heterogeneity in the health benefits at the coast, and shows that previous studies that have considered the coast in its mixed form may have substantially underestimated the effects of the most pristine environments at the coast. In sum, although the sample was not representative for the wider population, the strong evidence about the benefits of natural compared to urban environments in general (e.g., Hartig et al., 2014) suggests that it is safe to say that people in general can gain most health-benefits at the natural environments at the coast.

3.1. Scientific yield of Chapter IV

The study described in Chapter IV focused on beaches to be able to assess their effects on both psychological and physiological parameters of mental health more thoroughly. Beaches were identified as being among the most natural and thus psychologically restorative environments at the coast, and their popularity justified the societal relevance of the study. Four studies in the literature had investigated how exposure to beaches impacted psychological and physiological parameters of mental health, but these studies were characterized by essential limitations that inhibited to draw solid conclusions about the effects of the coast (Anderson et al., 2017; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015). More specifically, the results of three of these four studies were biased by the physical activity by the participants (e.g., roaming free, beach walk vs indoor sedentary control; Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015), and the one other study compared the effects of remote beaches with those of an indoor control, which made it impossible to distinguish outdoor-indoor effects from the beach-urban effects (Anderson et al., 2017). By implementing a virtual-reality experiment with physiological and psychological measurements, the effects of physical activity could be ruled out and the effects of beaches could be compared with those of green and urban environments, albeit in virtual reality. As such, the results of the study described in Chapter IV disclosed for the first time that virtual exposure to beaches causes a lower breathing rate than to urban environments and a lower sympathetic arousal than to green environments. As such, in the framework of White et al. (2020), it links indirect exposure to the coast to the physiological restorative pathways (Figure 38). One could argue that this study merely illustrates that the human mind and body are functionally linked to each other – something that a lot of previous psycho-physiological studies have already demonstrated (Cacha et al., 2019; Cacioppo et al., 2007) – and that our results merely replicate the results of Chapter III or those of White et al.'s picture-rating study that showed that blue spaces are rated to be more psychologically restorative than green and urban environments (White et al., 2010). That is true: the results of Chapter IV simply confirm that the mental benefits of the coast are also accompanied with physiological benefits and suggest that beaches (i.e., a 'blue space') are better than green and urban spaces. Furthermore, since the exposure was transferred via virtual reality and only visual and auditive stimuli were presented, one could argue that the full multi-sensorial effects of the coast could not have been measured. That is also true: previous methodological comparisons have illustrated that virtual reality hampers the ability to improve positive mood (Browning et al., 2021; Browning, Shipley, et al., 2020), and we also did not observe an increase in positive mood in Chapter IV. It remains a question as to whether real exposure to beaches would induce positive mood and whether the accompanying physiological pathways would change along. Nevertheless, the results of Chapter IV provide new perspectives about the effects of beaches without the interference of physical activity. It incites us to reflect about the origin of the effects and about the internal psycho-physiological mechanisms. For example, one could hypothesize that the benefits of beaches are the result of psychologically learned associations in early life or of evolutionary hardwired physiological drivers (Stevenson et al., 2018; Ulrich et al., 1991). Furthermore, it hints to the hypothesis that exposure to the coast impacts the same physiological pathways as those that are dysregulated in the case of mental ill health, which would explain why the coast benefits self-reported general health. Perhaps more important is that the study also demonstrated that the self-reported stress-reducing effects of beaches were more effective than those of green environments for participants with moderate levels of initial stress. Previous research had shown that coastal environments are perceived to be more restorative than green spaces (Elliott et al., 2023; White et al., 2010; White, Pahl, et al., 2013; Wyles et al., 2019). The results presented in Chapter IV contribute to this knowledge, and highlight that beaches may be particularly effective for those who actually need it. Thus, by shedding light on the physiological reactions to the coast, this study presents a new milestone by strengthening the body of evidence about the mental benefits of the coast and enhancing our understanding about the physiological mechanisms that may be active behind these effects.

3.1. Scientific yield of Chapter V

Chapter V and Chapter VI aimed to link the epidemiological effects of the coast in the previous chapters to the social structuring of coastal visit behaviors. Chapter V describes an online survey that gathered information about the visit frequency, activities, experiences, social company, and reasons for not visiting the coast more often alongside the demographic, socio-economic, and health characteristics of a representative sample of Flemish inhabitants (N = 1939). Before the start of the design of the survey in Chapter V, two studies published in scientific journals had illustrated that coastal leisure involves many types of activities in many different coastal environments, and that different kinds of individuals are likely to exhibit different coastal leisure activities (Boyd et al., 2018; Elliott et al., 2018). Despite this knowledge, scientific studies that investigated the effects of coastal exposure on health had usually neglected the characteristics of coastal visits (White et al., 2020). Furthermore, the effects of the social company at the coast and the embeddedness of coastal visit behaviors in individuals' lifestyle habits had almost completely been disregarded, despite being repeatedly mentioned in conceptual frameworks (e.g., Hartig et al., 2014; White et al., 2020). Many nations' coastal tourism offices already gathered data about the use of the coast and the experiences gained at the coast (e.g., Westtoer and De Kust, 2018). However, these data typically lack information about peoples geo-demographic, socio-economic, and health characteristics, which makes it less suitable for research. Thus, it was clear that new data was required that was openly-available and aimed towards solving research questions (instead of mainly serving the tourism sector). Chapter V explains the relevance, potential uses, and quality of our dataset, and explains how the chosen questions and items are relevant for addressing many research questions within the OHH and blue space literature. For example, the dataset holds the necessary information to investigate matters of 'coastal epidemiology and accessibility', 'health and psycho-physical experiences', 'social relations', and 'issues of time, season, and weather' (Table 9, page 119). The descriptions of the univariate data in Chapter V are immediately showing the commonality and variability of the queried coastal visit behaviors. For example, Figure 20 shows that two thirds of the respondents (67%) had visited the coast in the previous year, that the most common activities are strolling on the dike, eating out, and walking on the beach, that the majority of respondents often enjoys the sea air, the view, and has a good talk, and that the coast is most often visited with a partner. The published data descriptor (Hooyberg et al., 2024)also sets an example for other researchers and tourism agencies to publish their data about coastal leisure activities according to the FAIR principles. Thus, the openly-available data presented in Chapter V not only complements previous data from national coastal tourism offices, but also allows researchers to perform exploratory and confirmatory analyses cost-effectively.

3.1. Scientific yield of Chapter VI

Chapter VI used the data from the preceding chapter to investigate the social structuring of coastal leisure activities and social company for those who visited the coast in the previous year. By doing so, it took a completely different approach than the univariate descriptions of people's coastal visit behaviors reported about previously (Boyd et al., 2018; Elliott et al., 2018). Instead of taking an epidemiological perspective and focusing on what types of activities are performed by who, it focused on what distinguishes individuals from each other based on their full activity profile. More specifically, Bourdieu's distinction theory postulates that an individual's behavior, lifestyle habits, and conscious or unconscious choices are means to strengthen or improving that individual's position in the social space (Bourdieu, 1984). Bourdieu argues that distinctions between individuals can be captured best by dichotomizing their behavior as extremes (e.g., doing something often or always: Yes or No) and mapping them along orthogonal dimensions by means of multiple correspondence analysis (MCA; Hjellbrekke, 2018). In Chapter VI, this was done with 32 coastal leisure activities (e.g., walking at the beach, strolling on the dike) and 7 types of social company (e.g., with partner, with friends, alone). By comparing the covariations among these activities and social company at an individual level, the analyses revealed four relevant structuring dimensions. Consequently, ascending hierarchical cluster analysis was used to cluster individuals together based on their locations along the dimensions, which resulted in the identification of five clusters of individuals with distinct visit profiles. Hereafter, we briefly discuss the meaning of these dimensions and clusters in relation to the other chapters within this dissertation. For detailed associations and patterns between the included variables, we refer to the Results and Discussion sections of Chapter VI.

The four structuring dimensions revealed in Chapter VI emphasize that there is a considerable amount of variation in the visit frequency or desire to visit the coast (dimension 1), type of environments visited (dimension 2), the social company during the visit (dimension 3), and the purpose of the visit (dimension 4). The first dimension highlighted that the level of 'engagement' was associated with the visit frequency and potentially also with the desire to visit the coast more/less often relative to others. The previous literature suggested that the visit frequency is crucial for transferring any of the coast's health benefits (Elliott et al., 2023; Geiger et al., 2023). As such, it adds to the previous knowledge by highlighting that the visit frequency on both the visit level and on the level common vs. uncommon activities is what distinguishes coastal visitors best from each other. The second dimension marked the importance of the environment that people visit at the coast. Earlier, we observed that natural coastal environments are rated to be more restorative than more urban coastal environments (Chapter III). The second dimension shows that across different age groups and genders, people vary according to whether they solely favor urban environments at the coast, solely favor natural environments at the coast, or favor both. Crucially, it also showed that activities in natural versus urban environments are associated with a different social company: activities in natural environments were more typically done in the presence of kids, while urban environments more without kids. As such, this second dimension adds a new and social layer of complexity to understanding the contexts (e.g., natural vs. urban) in which the coast is visited. The third and fourth dimensions explicitly pointed to the social company during the visit as being an important structuring factor. More specifically, dimension 3 indicated that the coastal visits vary according to the social company (dimension 3), i.e., with at the extremes distinguishing visits with family (e.g., with partner, kids, (grand-)parents) from visits without family (e.g., alone, with friends, with a club). Alternatively, dimension 4 indicated that visits can be distinguished based on the purpose of the visit: whether the visit is about strengthening social bonds or about focusing on exploring the coast. Before this study, a relatively little amount of studies had demonstrated the value of family-interactions at the coast (Ashbullby et al., 2013) and the value of a friend when safety is a concern (which happens mainly in urban environments; Bell et al., 2015; Johansson et al., 2011; Staats and Hartig, 2004). Thus, the third and fourth dimension highlight that coastal visits and visitors vary according to the social company they bring to the coast and according to whether they would like to focus their attention on strengthening social bonds or on exploring the environment.

The five clusters of individuals identified in Chapter VI demonstrated that the visitor profiles particularly vary according to the visitors' demographic, socio-economic, and health situation. More specifically, visitors with a 'generalist' visit profile have a relatively larger share of highly educated middle-aged parents living with a partner and kids, those with an 'engaging in the city' profile have a relatively larger share of younger or retired individuals, those with a 'disengaging in the city' profile a relatively larger share of retired couples, those with a 'disengaging in the nature' a relatively larger share of young and mentally and socially deprived individuals, and those with an 'engaging in nature' profile a relatively larger share of those who live with more than one person and who work or reside at the coast. These clusters further strengthen the evidence about the value of the visit frequency for gaining positive experiences at the coast more often, and that those who visit the coast less frequently (individuals who are retired or young mentally and socially deprived) are likely to encounter the positive effects of the coast less often (Elliott et al., 2023; Geiger et al., 2023). In sum, the dimensions and clusters demonstrate that a person's relation with the coast should not solely be expressed in terms of the visit frequency, but also by the visited environment, social company, and purpose of the visit, all of which are related to who individuals are, both demographically, socio-economically, and in terms of health.

3.2. Overall scientific yield

Overall, the four empirical studies and data descriptor in this dissertation provide evidence that residents along the Belgian coast report a better health than their inland counterparts, that visits to the coast would be more beneficial if they happen in natural coastal environments, that virtual exposure to beaches downregulates the breathing rate and sympathetic nervous system than more than urban and green environments, and that the frequency and types of coastal visits are socially structured. As such, these results contribute to answering the overarching research questions A and B.1 defined by the SOPHIE SRA (H2020 SOPHIE Consortium, 2020).

A. What is the evidence for the effects of coastal environments on human health?
• Coastal residents in Belgium report to have a better general health than inland residents (Chapter II). • Natural coastal environments are rated to be likely to provide psychological restoration Chapter III). • Beaches relax psychological and physiological stress (Chapter IV). • People report various positive mental and physical experiences when recalling previous coastal visits (Chapter V).
B.1. With regards to mechanisms and pathways: through which interactions (type of activity, duration etc.) with different types of coastal environments does human health improve?
• Via residing in proximity to the coast (Chapter II).

- Via interactions with natural environments at the coast (Chapter III).
- Via interactions with beaches (in virtual reality; Chapter IV).
- There is a lot of variation in the frequency, type, season, and characteristics of coastal visits (Chapter V).
- People's activities and social company at the coast are socially structured (Chapter VI).

The results presented in this dissertation also contribute to understanding the effects of the coast on human health in the framework of White et al. (2020; Figure 38; see also Figure 4 in the Introduction). More specifically, Chapter II linked residential proximity to the four hypothesized mechanisms described in Hartig et al. (2014): less mental distress refers to restoration, increased physical and social activity refer to instoration, and less exposure to harmful air pollutants refers to mitigation (White et al., 2020). Chapter III used indirect exposure to the coast via pictures to evaluate the psychological restorativeness, and the moderating influence of environmental components, which can be considered as situational moderators. Chapter IV used indirect exposure to beaches via virtual reality to reveal the psychophysiological effects, while considering the moderating role of the individuals' initial stress levels. Chapter V and VI linked individual characteristics (including general health as an individual moderator and as an outcome) to intentional visits and the visit frequency and characteristics, while capturing people's restorative experiences from those visits. The visit characteristics included the activities performed and the social company during the visits, which may both refer to situational moderators as to instorative mediators.

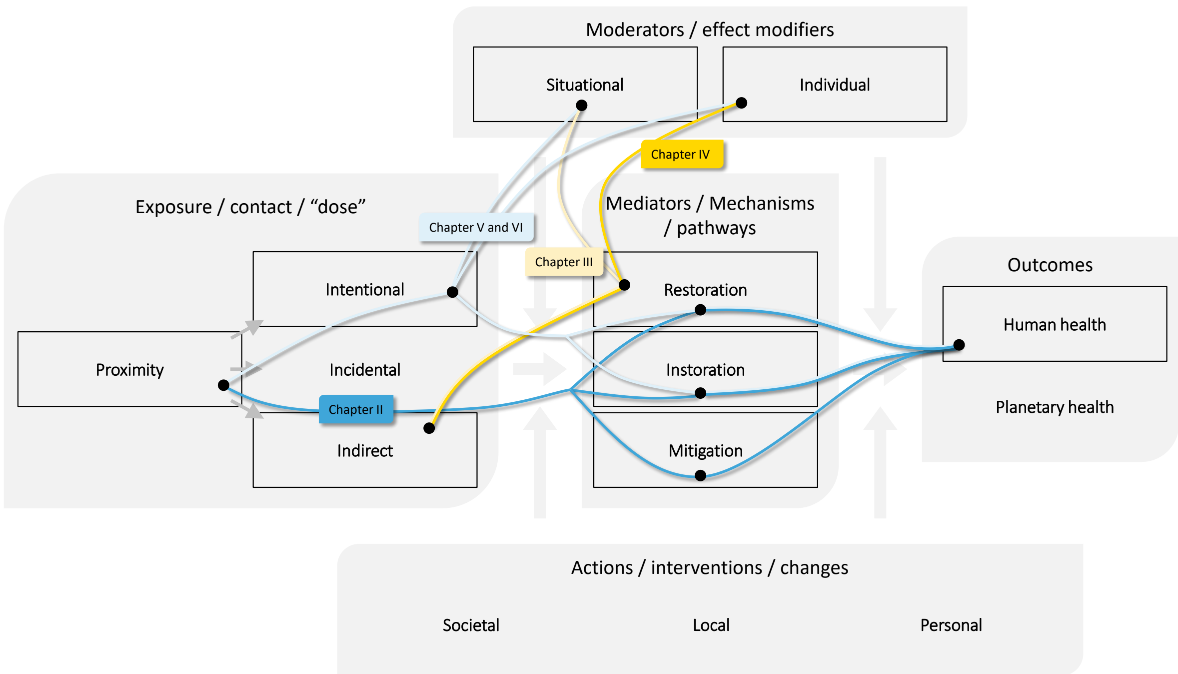


Figure 38: Overview of the contributions of Chapter II, III, IV, V, and VI to the relationships between exposure to the coast and human health depicted by White et al. (2020).

3.3. Methodological highlights

As a final note, the generated insights would not have reached the same quality and quantity without some innovative methodological advances compared to the previous literature. Below, a selection of methodological highlights is listed. These highlights also seem to be valuable contributions to the literature.

- Chapter II went beyond the commonly assessed bi-variate relationships in OHH-related epidemiological research (e.g., Wheeler et al., 2012; White, Alcock, et al., 2013) by having performed four mediation analyses with bootstrapped confidence intervals on a large dataset (N = 60,939).
- In picture-rating experiments, previous research typically standardizes the photographs to include or exclude typical landscape features, such as trees, people, water, buildings, animals, steep slopes or mountains, and vehicles, and most previous research mostly controlled for them only qualitatively (Browning et al., 2021; White et al., 2010). The pictures used in Chapter III were not standardized for these features in a clear-cut manner to maintain the realism of the environments depicted on the pictures (although they were shot under clement weather conditions and without crowding), which is considered an improvement. Furthermore, every environmental component was quantified by its relative surface area on the picture (as a measure of their dose) and linked to the ratings. Importantly, the pictures were taken and edited in such a way that they had a similar sharpness, zoom, perspective (i.e., not tilted and the horizon always approximately in the center), lightness and darkness (e.g., details visible in the shadows), color tone, saturation, and contrast, all of which may be methodological artefacts that may influence the rating of a picture and that have hardly been reported in the previous literature (Yarbus, 1967). As such, the analyses could add evidence to the existence of a dose-effect of vegetation and not of water.
- The study design of Chapter IV was perhaps the most innovative, because it maximized the analytical power by considering the beach as the ‘control’, and not the urban environment, as in most previous studies (e.g., Triguero-Mas et al., 2017; Vert et al., 2020). As such, the effects of beaches could be compared to those of urban and green environments. The design also had each participant exposed to two types of environments (i.e., beaches and green or urban) to be able to detect within-person differences in their responses. Since there was a baseline measurement before the exposure, any carry-over effects could be analytically controlled for. Another innovative trait of this study is that 164 participants (i.e., 54 or 55 per group) of various socio-demographic backgrounds were recruited with a media-campaign and without monetary incentives. This is a rather high number compared to other previous studies with simulated nature exposures (Browning et al., 2021). As such, financial resources were saved, and the lab could be equipped with a device that could measure a relatively large number of physiological biomarkers of stress simultaneously (i.e., NeXus-10 MKII, Mind Media). Whereas previous research on the effects of the coast on human health was typically restricted cardiovascular and electrodermal measurements (Anderson et al., 2017;

Triguero-Mas et al., 2017; Vert et al., 2020; White et al., 2015), the acquisition of the device enabled to additionally monitor the breathing rate and muscle tension.

- Chapter V was particularly innovative due to the combination of many visit-related and individual-related characteristics in an openly available and described dataset. More specifically, it contains information about the visit frequency, type and season of the visits, the self-rated frequency of coastal leisure activities performed, experiences gained, the social company, and reasons for not visiting the coast more often during previous coastal visits, and the geo-demographic, socio-economic, and health characteristics of the individuals. As such, it captured a year-round perspective on citizens' coastal visit behavior. Previous surveys typically asked for visits in the last four weeks (e.g., MENE survey in England and BlueHealth International Survey), which led to missing data on year-round coastal visit behaviors.
- Chapter VI is probably the oddest in the field of research about the effects of the coast on human health, yet perhaps the most rewarding study in this dissertation. Most distinctively is that it brings in sociological perspectives by showing the value of complex, multivariate, and geometrical data analyses that use both individuals and their behaviors as analytical unit, i.e., MCA and AHC. By revealing how coastal visits are socially structured, and which visitor profiles can be distinguished, it mapped many factors that are potentially interesting in the context of the effects of the coast on human health.

Given these methodological highlights, the research presented in this dissertation not only contributes to providing evidence and understanding of the pathways outlined by White et al. (2020), but also illustrated how methodological innovations can lead to the acquisition of more advanced knowledge and to a more efficient use of analytical and financial resources.

4. Future research

The knowledge acquired in this doctoral research has contributed to the evidence and our understanding about the pathways in the conceptual framework of White et al. (2020): how different ways of exposure to the coast impact human health, how restorative, instorative, and the mitigative mechanisms may effectuate the effects on health, and how situational and individual factors modify the effects (Figure 38). However, not addressed was how societal, local, and personal actions may accelerate the proliferation of the effects of the coast. Nevertheless, the knowledge acquired in this doctoral research may nurture the development of societal, local, and individual actions in the future, particularly in the health care sector. The knowledge acquired from this doctoral research has also contributed to answering research questions A and B.1 of SOPHIE's SRA. However, not addressed was how interacting with the coast increases the risk of disease and/or physical issues (i.e., B.2), how increasing the human use of coastal environments affects the coastal and marine ecosystems and biodiversity (i.e., C), and how OHH interactions can be optimized in order to obtain physical and mental health benefits in a sustainable manner for all people and species (i.e., D). Future research should remain to address the pathways in the framework of White et al. (2020) and the four research questions proposed by SOPHIE's SRA (i.e., A-D), because many fundamental and applied knowledge gaps remain. Each of the studies described in this dissertation has a section about suggested directions for future fundamental and/or applied research, and Chapter V also listed a set of research questions that can be addressed with the gathered data: i.e., with regard to the social structuring of coastal visits and with regard to ongoing investigations in the literature (i.e., coastal epidemiology and accessibility, health and psycho-physical experiences, and social relations).

The next sections first describe what fundamental knowledge should be gathered to increase the evidence and the understanding about dose-response relationships and bio-psycho-social resilience. Then, the focus is on interesting follow-up research in the light of potential future actions. More specifically, the knowledge acquired in this doctoral research should be followed by investigations on the value of the coast's benefits for health care, on the economic values of the effects of exposure to the coast on health, and on how knowledge about the effects of the coast on human health may lead to a more sustainable interaction with the ocean.

4.1. Dose-response relationships and bio-psycho-social resilience

First and foremost, future research should aim to increase the evidence and our understanding about the effects of exposure to the coast on human health by focusing on dose-response relationships and bio-psycho-social resilience. Previous research has largely focused on investigating the effects of residential proximity and the number of actual visits to the coast on self-reported mental or general health (Elliott et al., 2020, 2023; Geiger et al., 2023; Pool et al., 2023; Wheeler et al., 2012; White, Alcock, et al., 2013; S. L. Wood et al., 2016). Future research should remain to investigate how coastal residents differ from inland residents in the frequency and types of coastal visits made and the resulting effects on self-reported and objective measures of mental health, general health, and well-being. The results of Chapter VI suggest that future research should also assess how the visit characteristics impact the health benefits and how the total visit profile and dose results in the effect sizes of relevant health outcomes. As such, dose-response relationships should be gathered for different modes of exposure and for populations with different geo-demographic, socio-economic, or health characteristics.

Dose-response relationships should not only consider the diversity in the doses, but also the diversity in potential health outcomes. Most crucially, it is still relatively unknown how quickly, how strongly, and how enduringly diverse emotional, cognitive, and physiological measures respond to exposure to the coast, and how these effects change for repeated exposure to the coast (White et al., 2020). More specifically, Chapter IV demonstrated that exposure to beaches provides stress-relief, improves mood, and calms the breathing rate and sympathetic nervous system activity relative to urban and green environments. All of these psychophysiological changes have widespread impacts throughout the human body (Cacioppo et al., 2007). Furthermore, since the psychological, physiological/physical, and social dimensions of health are inextricably linked to each other (Linton et al., 2016; Lovell et al., 2018), the benefits of the coast for mental health may influence the physical and social dimensions of health as well. As such, the coast may also improve human health via lag-effects. For example, the coast's ability to draw the attention towards the environment may increase a person's awareness or mindfulness of the present moment and enable a better view of a person's own mental and physical status and requirements for health and other needs in life towards the future (Lymeus et al., 2018, 2022). Coastal environments may also be particularly good for triggering the leisure state of mind, a mental state that has been reported to be crucial for enabling many of the health benefits of the coast (Gammon & Jarratt, 2019). As such, examples of symptoms on which exposure to the coast may have a restorative effect include a decreased or unstable mood, anxiety, depressive thoughts, (chronic) stress or maladaptive coping with stress, decreased cognitive or physical performance and capacities, a poor emotional well-being, maladaptive repetitive negative thinking and rumination, decreased self-confidence, low levels of mindfulness, feelings of loneliness, hyperventilation, poor body posture, tensed muscles, headaches, intestinal dysregulations, sub-optimal microbiome communities, and probably many others (Jones et al., 2021; Lopes et al., 2020; Neale et al., 2021; Schleifer et al., 2008; Selway et al., 2020; Thompson & Wilkie, 2020; Triguero-Mas et al., 2017; Vert et al., 2020). Since there is a lot of (indirect) literature that supports these claims, it seems relevant for future research to assess how exposure to the coast impacts on these primary and secondary health outcomes.

Exposure to the coast may potentially help the brain (e.g., limbic system) and body (e.g., vagus nerve) in training particular pathways and reflexes that may ultimately result in strengthening a person's bio-psycho-social resilience over time (White et al., 2023), similarly as what practicing mindfulness and physical exercise do (Depledge & Bird, 2009; Herman et al., 2005; Lymeus et al., 2018; Russell & Lightman, 2019; Schneiderman et al., 2005; White, Pahl, et al., 2016). More specifically, being exposed to the coast repeatedly may help to train the human brain and body to better adapt to unusual or uncomfortable situations, such as physically challenging situations (e.g., walking in the dunes), mentally stressful situations, inclement weather conditions, and processing relatively unknown stimuli (e.g., sceneries, sounds, scents, situations). As such, functional and structural changes may develop, such an increased functionality of the vagus nerve, and an increased size and activity of the amygdala and other parts of the limbic system in the brain, alongside an improved physical condition, which also has its mental benefits (Herman et al., 2005; G. W. Kim et al., 2010; Kühn et al., 2017). This would allow a person to avoid stressors better, cope with them better, and recover more quickly from stress, and as such strengthen bio-psycho-social resilience (White et al., 2023). Thus, future research should further explore the effects of the coast on a diversity of primary and secondary outcomes, together with their long-term effects on resilience, the (neuro-) psycho-physiological pathways and the moderating roles of individuals' characteristics. In essence, this boils down to investigating how the state and abilities of living human beings changes in response to exposure to the coast.

4.2. Investigating the value of the coast's benefits for health care

If there is more knowledge and support for the benefits of exposure to the coast on patients' health, these benefits could be used to prevent and treat the antecedents of mental disorders, the disorders itself, or to ease the symptoms of a decreased mental health (Britton et al., 2023; Fullam et al., 2021; Juster-Horsfield & Bell, 2021; Shanahan et al., 2019). The introduction demonstrated that the mental health care sector is overloaded with patients with symptoms of poor mental health, and that the existing therapies are often inaccessible, not efficient enough, and still result in a high rate of relapses (Dedoncker et al., 2021; Triliva et al., 2020; WHO, 2019, 2022b). Coastal environments provide a relatively cheap, publicly available, socially acceptable, and potentially highly efficient way of increasing patients' mental health (Charveriat et al., 2021; Filipova et al., 2020; Short et al., 2021). However, fundamental research about the dose-response relationships and bio-psycho-social resilience should be complemented with applied research about whether and how the coast's benefits should be integrated in health care applications.

A first step should involve testing whether the application of the ocean's benefits in health care is clinically interesting and actually cost-effective. There are various ways by which the benefits of the coast can be implemented. For example, the patient may be brought to the coast, or the coast may be brought to the healthcare facilities by using virtual reality or another form of simulated coastal environment as distractions during clinical procedures or to speed up recovery after clinical interventions (Kouijzer et al., 2023; Tanja-Dijkstra et al., 2014; White et al., 2018). The cost-effectivity of these use-cases should be compared to that of other existing therapies and alternatives, to their joint implementation, or to a 'no care' scenario. It should be acknowledged that these cost-effectiveness relations can differ depending on the clinical health situation, the way the person is exposed to the coast, and various individual characteristics, such as the demographical and socio-economic situation, the patient's expectancies, motivations, values, personality and nature connectedness (Davison et al., 2021; Hignett et al., 2018; Sterckx et al., 2023; Subiza-Pérez et al., 2021; Van Der Pligt & De Vries, 1998; White et al., 2020).

A particularly effective way of transferring the ocean's benefits to patients with a poor (mental) health would be via 'blue social prescribing' (or 'coastal visits on prescription'), i.e. the practice of health care workers to prescribe or recommend a patient to visit the coast to improve health (Alexander & Brooks, 2021; Garside et al., 2020; Kondo, Oyekanmi, et al., 2020; Koselka et al., 2019; P.-Y. Nguyen et al., 2023; Robinson et al., 2020; Shanahan et al., 2019; Tester-Jones et al., 2020). According to the WHO, social prescribing is "*a means for health-care workers to connect patients to a range of non-clinical services in the community to improve health and well-being*" (WHO, 2022a). Green social prescribing refers to "*the practice of supporting people to engage in nature-based interventions and activities to improve their mental and physical health*" (NHS England, 2024). Given these definitions, restorative environments at the coast can be considered as the 'non-clinical service', and blue social prescribing would not necessarily need to include social services (e.g. link workers, supportive organizations) in the community. Crucially, the success of blue social prescribing will depend on many factors on the sectorial and individual level (Fullam et al., 2021; WHO, 2022a).

At the sectorial level, future research should first evaluate whether the targeted health care system (e.g., on a regional level) is fit for adopting blue social prescribing and other ocean-inspired therapies. For example, there may be lack of agents to support the patient with its exposure to the coast, there may be lacking top-down regulations about the referral routes between primary care services, patients, link workers, and health care, or the way of communicating between the required actors needs to be optimized (Fullam et al., 2021; Sterckx et al., 2021). Health care professionals that would be most suitable for prescribing the coast would include general practitioners, psychologists, and psychiatrists, because they are typically those caregivers that first come into contact with patients with mental ill health and are crucial for the choice of therapy.

At the individual level, patients would obviously need to be advised to visit the coast in such a way that the likelihood of gaining the required health benefits is maximized. However, the prescribed dose should also match with a person's lifestyle, abilities, pursuits, and challenges in life, as well as with their social position and cultural habitus. For example, patients may encounter many different barriers or constraints that may prevent the adherence of visiting the coast, such as other financial, social, practical, or motivational priorities (Kondo, Oyekanmi, et al., 2020). When patients have limited access to the coast, alternative exposure options, such as virtual-reality, documentaries, or even hypnosis, might be targeted (Browning, Mimnaugh, et al., 2020; Orr et al., 2021; Tanja-Dijkstra et al., 2018; White et al., 2018; Yin et al., 2018). There might also be a considerable difference between blue and green social prescribing: while green environments tend to be spread out across land and be relatively accessible for most people, the coast may be especially attractive therapy for those who live near it, but less for those who live further away. Risks, both intrinsic (e.g., fears of water) and extrinsic (e.g., injury) ones, should always be outweighed against the potential benefits. Future research should investigate the risks associated with exposure to the coast according to research question B.2 of SOPHIE's SRA (H2020 SOPHIE Consortium, 2020). Communicating the (potential) effects of the coast for human health to caregivers and patients might not convince them enough to start implementing blue social prescribing practices, and capturing the perspectives and attitudes of both caregivers and patients towards the ocean-inspired therapies will also be crucial (Kondo, Oyekanmi, et al., 2020). Potentially, the method of communication by which information is transferred between caregivers, patients, and policy-makers may be crucial, and the effect of different communication styles on the patients' adherence should be assessed (Ha & Longnecker, 2010; Haskard Zolnierek & Dimatteo, 2009). Given the environmental, individual, and clinical factors that may determine the success of blue social prescribing, future research should follow-up knowledge gaps and potential areas of improvement once implemented. For example, the quality of interventions can be monitored using regular evaluation of the structural, theoretical, scientific, environmental, and societal needs (Sterckx et al., 2024).

4.3. Valuing the health-related economic consequences of exposure to the coast

The better mental health of citizens due to living near or visiting the coast would potentially result in substantial economic changes for society via increases in the quality of life and avoided costs for the health care sector (Buckley and Chauvenet, 2022; Czajkowski et al., 2015; Figure 39). If the benefits of the coast for human health are better-evidenced and better-known, the coast may be used more frequently, which may also result in economic gains for the blue tourism sector (Dodds and Holmes, 2019; Knapp and Vandegehuchte, 2022; Figure 39). Economic gains may be accompanied by economic losses, for example for the pharmaceutical sector when blue social prescribing would lead to a decreased use of medication for mental health.

Although much more research is required to finetune dose-response relationships for coastal visitors and residents, the data from Chapter II already allows to make a couple of provisional estimates about the economic value of living near the coast. More specifically, the results of Chapter II indicated that residents who live <5 km from the coast reported a 0.131 increase in health (95% CI = [0.003, 0.259]) on a five-point scale from very bad (0), to very good (4). Those estimates let us assume that the entire population of the ten coastal municipalities (N = 339,736 in 2023, Rijksregister and Statbel, 2023) on average experiences those health benefits. Hereafter, these health-estimates are translated to monetary values in different ways.

- One way of interpreting the health benefits for coastal residents is via quality adjusted life years (QALY). One QALY represents a year lived in perfect health, and would correspond with a self-reported general health status of 'very good', whereas 0 QALY's means death or living in a state worse than death. Let us make the same assumption that the Office for National Statistics of the United Kingdom makes in their online report (which they indicate is work-in-progress): a self-reported general health value of 'very good' is equivalent to a QALY of 1 and 'very bad' to a QALY of 0.2, and a one-step decrease in self-reported general health would be equivalent to a loss of 0.2 QALY's (Office for National Statistics, 2023). The estimated health benefits of the coastal residents (0.131, 95% CI = [0.003, 0.259]) were multiplied to the population size and expressed in terms of QALY's via this rule. With these calculations, it seems justified to say that living nearer the coast result in a gain of 8,901 QALY's on a population level along the Belgian coast.

- It has been assumed that 1 QALY benefits society with approximately the per capita GDP (Carrico et al., 2023). In Flanders, the per capita GDP is estimated at 45,200 euro (Statistics Flanders, 2023). Thus, multiplying the per capita GDP by the gain in QALY's suggests that the health benefits of coastal residents returns Flanders with 402,328,961 euro per year.
- The economic benefits can also be calculated without QALY's. More specifically, a subjective well-being valuation study revealed that the lost value of moving from good/excellent health to fair/poor health is 1.8 times the median equivalized annual household income in the United States (Brown, 2015). It should be noted that income and preferences are likely to differ in the Belgian population. However, neglecting these differences provide the provisional estimate that the better general health of an average coastal resident in Belgium results in a gain of 0.2358 times the median equivalized annual household income per year. Since the coastal population is characterized by a relatively older age and different socio-economic situation, of which no estimates seem to have been described, it does not seem appropriate to upscale these estimates to the coastal population level.
- The economic value of the health benefits of coastal residents can also be expressed by means of the avoided costs for the health care sector, because the coastal residents' changes in self-reported general health also associate with changes in the number of visits to a general practitioner. More specifically, post hoc analyses on the data obtained from Sciensano for performing the study in Chapter II reveals that moving from fair to good health (which is the range in which the change in 0.131 operates) is associated with a decrease of 2.0372 (SE= 0.1474, $p<0.001$) visits to a general practitioner per year. A recent study reported the insurance costs and out of pocket costs that are associated with changes in visits to a general practitioner (Vranken et al., 2023). This information reveals that the better self-reported general health of coastal residents results in 2,223,786 euro avoided insurance costs per year and 326,986 euro avoided out of pocket costs per year.

So, what we can learn from these explorative estimations is that there are various ways by which the health benefits of exposure to the coast can reduce economic burdens for individuals and societies, and that these economic values can be quantified as both the value of increased health as the value of avoided health care costs (Figure 39). However, a lot of assumptions had to be made during the abovementioned calculations, and more accurate economic estimates will be required. Therefore, more accurate information about how people's visits to the coast are linked to their socio-demographic situation, and which health effects are experienced. Particularly interesting would be to assess how different doses of exposure to the coast affect the health-related quality of life, because this is an often-used measure to which economic values have already been linked (Bockarjova et al., 2020; Whitehead & Ali, 2010; Zhong et al., 2021).

Next to health-related benefits, the evolution in the direct and indirect uses of the coast can also be expressed in economic values (Figure 39). Direct uses involve actively spending time at the coast. Locally, estimates of the local tourism agency have shown that an average visitor at the Belgian coast spends 45 euros, which is 8 euros more than the costs spent for living in daily life, and that in total all Flemish tourists at the Belgian coast would result in 498 million euros in economic revenues for the coastal tourism sector, annually (Westtoer & De Kust, 2018). Globally, coastal tourism is estimated to constitute 5.2% of the global gross domestic product or a value of 4.6 trillion US dollar (Northrop et al., 2022). The indirect uses of the coast can also be quantified. For example, there is currently an increasing use of virtual reality in health care settings (Dhar et al., 2023; Kouijzer et al., 2023), and some therapists informed me that these uses often include coastal or underwater scenes. As such, the industry that makes and sells the required equipment for these virtual reality applications may also indirectly gain economic benefits. In sum, there are various ways by which the uses and effects of the coast on human health can be expressed in monetary terms, and the preliminary estimates presented here are pointing to potentially massive economic gains for society globally (Figure 39).

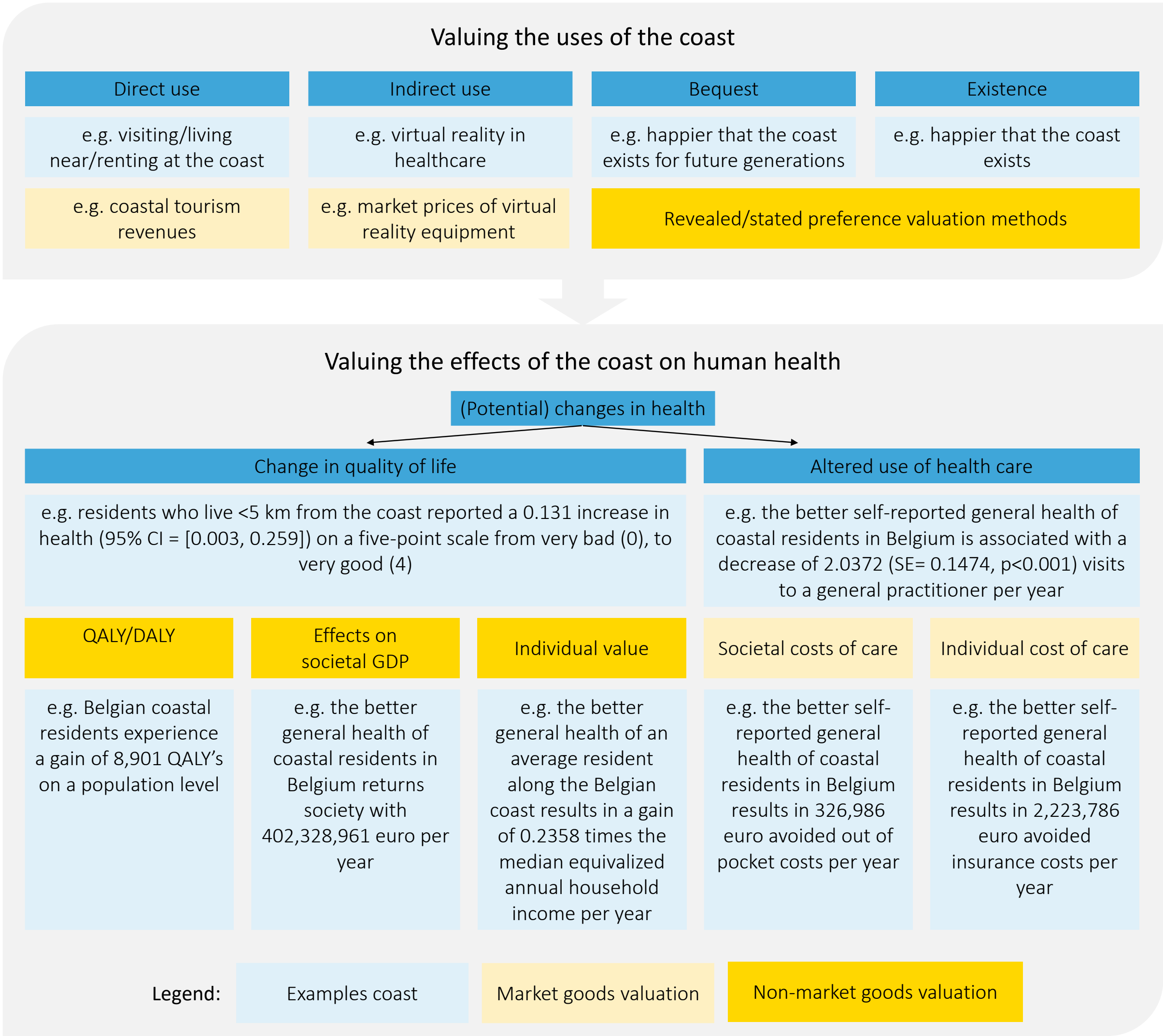


Figure 39: Conceptual overview of some of the economic gains of uses of the coast and of the effects of the coast on human health. The required valuation methods to calculate these gains are also suggested.

4.4. Enabling a more sustainable interaction with the ocean

Previous high-level reports have suggested that insights into the risks and benefits of interacting with the coast for (mental) health may foster actions towards a more sustainable and resilient use of the ocean (Borja et al., 2020; European Marine Board, 2013; Fleming et al., 2014, 2019, 2021; Pellens et al., 2021). These reports explain that more sustainable interactions may happen via a more sustainable coastal tourism sector and the spread of ocean literacy (i.e., educating people on how the ocean impacts them and how they impact the ocean). In the introduction, it was shown that the coastal exposure and experience are central for ensuring healthy communities and a healthy ocean (Chapter I.1; Figure 3), and both are essentially managed by the (coastal) travel and tourism sector (Borja et al., 2020; Soshkin & Calderwood, 2022). The travel and tourism sector depends on enabling physical, societal, political, and economical environments, and to make tourism sustainable, the sector requires environmental sustainability, socio-economic resilience, and a balance between tourism demand, pressures, and impacts (Soshkin & Calderwood, 2022). Before the COVID-19 pandemic, tourism was becoming problematic, because overcrowding started to put pressure on local infrastructures and natural and cultural assets, which were generally leading to more degraded local communities and economies (Calderwood & Soshkin, 2019). The coastal tourism demand was drastically reduced during the COVID-19 pandemic, and is now still recovering worldwide, the risks of overcrowding and the negative consequences on the ocean and on human health are still a concern (Soshkin & Calderwood, 2022). To reduce the risk of overcrowding, tourists would need to be dispersed in time and place, by making less popular destinations more attractive (Borja et al., 2020; Soshkin & Calderwood, 2022). This can be done by investments in transport options, infrastructure, and liveability in secondary destinations, what would increase profits in these destinations and decrease overcrowding at the more popular destinations. As such, both the liveability for local communities and the visitors' experiences can be maximized, while the economic resilience is strengthened and the environmental impacts can be kept manageable (Soshkin & Calderwood, 2022). In Flanders, it is expected that health is becoming one of the megatrends for tourism (Toerisme Vlaanderen, 2020). More specifically, tourists are increasingly favouring destinations that consider their individual specific health requirements, including their dietary preferences, their need to get away from busy and crowded places, and their desire for strengthening their mental and physical resilience (Toerisme Vlaanderen, 2020). As such, that more natural environments are rated to be more psychologically restorative (Chapter III) adds leverage to conserving natural environments at the coast. However, the role of researchers for the coastal tourism sector has not yet been clarified, and the potential impacts of different tourism strategies on the coastal and marine natural environment requires more attention (Fleming et al., 2019). Therefore, future research should not only study the effects of the coast for human health, the application in the health care sector, and the associated economic consequences, but also how this knowledge would be applicable in the coastal tourism sector and sustainable OHH-inspired actions (H2020 SOPHIE Consortium, 2020).

Action requires knowledge, and spreading ocean literacy has been proposed as one of the key mechanisms that creates a culture of care and fosters pro-environmental behaviours among coastal tourism businesses, policy-makers, researchers, and users (H2020 SOPHIE Consortium, 2020). However, one should be careful when spreading literacy about the effects of the coast on human health, because it should not lead to more overcrowding or other pressures on the marine and coastal environment and the tourism sector. For example, advocating that spending time at the coast benefits health also requires the add-on of information about the importance of visiting more natural environments for acquiring benefits for human health, about the potential consequences on the natural environments, and about the how overcrowding could foster unsustainability rather than sustainability. In this context, it is interesting to note that there is an increasing amount of literature that shows that engaging more with nature is linked to a stronger connectedness to nature, which increases the likelihood for them to act in favor of those environments (Alcock et al., 2020; Berto & Barbiero, 2017; Britton et al., 2023; Rosa & Collado, 2019; Severin, Akpetou, et al., 2023; Whitburn et al., 2019). As such, visiting or residing near the coast may not only benefit individual health, but also environmental health and more support for (or less contestation against) sustainable adaptations along the coast. Across Europe, many innovative actions have already happened that have generally benefited the ocean, human health, and society, such as blue social prescribing, ecotourism, and citizen science (Pellens et al., 2021). However, future research is necessary to reveal the actual effects of these actions on human health, and how literacy can promote a sustainable use of the ocean and long-term human health. After all, the interactions between the ocean and human health still remain a tangled net of intertwined relationships (Figure 2), and there is still a lot of research to be done about how knowledge of the an altered (mental) health state influences the health of the ocean, and how the health of the ocean influences coastal tourism dynamics and the coastal exposures and experiences of the visitors (Fleming et al., 2019).

5. The future of this research topic

For this emerging transdisciplinary research field, it will be paramount to create clarity on the boundaries of the topic, to critically examine existing frameworks, and to communicate about the topic in a clear manner to fellow-scientists, policy-makers, the wider public, and other stakeholders. To do so most appropriately, an objective and transdisciplinary perspective should be adopted that is not open to ambiguous interpretation.

5.1. Setting boundaries

The specific approach to health that was conceptualized in the introduction allows for a transdisciplinary, objective, and unambiguous interpretation of health. The approach was built on a physics perspective on the universe to define health as the state and abilities of an entity defined in space and time, while disregarding the characteristics causality and desirability that were previously given to health. The specific approach to health has received its name in order to remind the user to remain specific and to not expand a concept to something more than it is. It was used to define the topic of human health in this dissertation: human health was conceptually restricted to how the state and abilities of all living human beings respond to exposure to the coast. According to this definition, the previously discussed dose-response relationships and factors of bio-psycho-social resilience can be perfectly be considered to be part of the topic. It is considered a strength that this is a highly fundamental approach and leaves little room for including applied research. Previously in this discussion, directions for future research towards potential societal applications were proposed, such as towards potential health care applications, economic valuations, or making our relationships with the coast and ocean more sustainable. However, these are topics with a differently defined entity. For example, investigations on potential health care applications are only about caregivers and patients, economic valuations are about economic entities, which can even be material, and investigations on sustainability matters may also comprise the state of ecosystems and their functions. Therefore, these topics are considered to be different research topics and not part of the topic of this dissertation. That the topic of this dissertation is restricted to fundamental questions does not mean that other research topics are irrelevant for it. Causalities between different research topics are inevitable. For example, findings on the fundamental effects of the coast can lead to more effective investigations on health care applications. Thus, when conceptualizing the specific approach to health in the introduction, it was described that there are a myriad of causalities than can be linked to an entity or a topic, and it is inappropriate to include particular causal entities and excluding others, because this creates ambiguity.

The specific approach to health does not set any boundaries on the underlying motivations for investigating the topic, although there should be a logical potential or actual link to the defined entity. For this emerging research topic, the motivation was that knowledge about the effects of the coast on human health can lead to several potential societal applications that may arise from the acquired knowledge, i.e., health care improvements and sustainable transitions. Thus, when communicating about this emerging research topic to the various stakeholders, one should remain specific, and notions about the topic should be separated from notions about the underlying motivation for investigating the topic. In this way, fellow researchers, funding agencies, policy-makers, and other stakeholders are given an accurate and clear view on the anticipated research activities and outputs, and interpretations should be univocal.

5.2. Updating White et al.'s (2020) framework

The aims of this dissertation were linked to the existing framework of White et al. (2020) to make a logical link with the previous literature and conceptualizations. This framework allowed to structure the potential modes of exposure, outcomes, and mediating and moderating pathways. However, the framework of White et al. (2020) does not perfectly align with the specific approach to health (Chapter I.2.2) and the definition of human health (Chapter I.2.3) presented in the introduction. The framework of White et al. (2020) considers the mediating pathways restoration, instoration, and mitigation as distinct from general human health. That the mediating pathways are brought up as mediators originates from the vast amount of literature that shows associations between these mediators and more general health outcomes (White et al., 2020). However, according to the specific approach to health and the definition for human health extracted from it, the distinction between mediators and general human health outcomes is inappropriate. According to the specific approach to health, human health is simply considered as the state and ability of human beings. Self-reported general health, which has been the operationalization of the concept ‘general human health’ in the literature (Elliott et al., 2023; Geiger et al., 2023; Wheeler et al., 2012, 2015; White, Depledge, et al., 2013), should be considered as just another state of a human individual, characterized by a specific organization of molecules in the brain that makes a person feel what it feels. Conceptually, it does not differ from other emotions, thoughts, behaviors, and states of a human body. As such, the concepts self-reported general health, social and physical activities, and the level of stress are all referring to the state and abilities of human beings, and the mediators and outcomes should be merged to the overarching concept ‘human health’ in the conceptualization of White et al.'s (2020) framework (Figure 40).

The specific approach to health also warns scientists to be cautious with using and interpreting mediation pathways, such as those conceptualized in White et al.'s (2020) framework and those analyzed in Chapter II and in Elliott et al. (2023). In these two latter studies, it was discussed that the visit frequency, and not necessarily residential proximity to the coast, explains the better self-reported general health of coastal residents via more social and physical activities and less stress during the visits. From a statistical point of view, the inclusion of different health outcomes in the same statistical (mediation) model may distort the power to reveal statistical significance. More specifically, a statistical (mediation) model subtracts the covariation between the different main and secondary predictors of interest from the variation that is needed to explain the association between the main predictor and the outcome. Consequently, statistical mediation analyses, such as those performed in Chapter II and in Elliott et al. (2023) are conceptually and statistically inappropriate. Thus, although the studies such as those in Chapter II or of Elliott et al.

(2023) have proven useful to fuel interest for the topic and to reflect on the appropriateness of these analyses, they seem best to be avoided in the future.

The framework of White et al. (2020) also states that 'planetary health' is one of the ultimate outcomes alongside human health, and it gives 'pro-environmental behaviors' and other individual attitudes with regard to sustainability as examples. According to the specific approach to health, the 'planetary health' label is too ambiguous, and the effects on pro-environmental behaviors should be considered as part of human health (Figure 40).

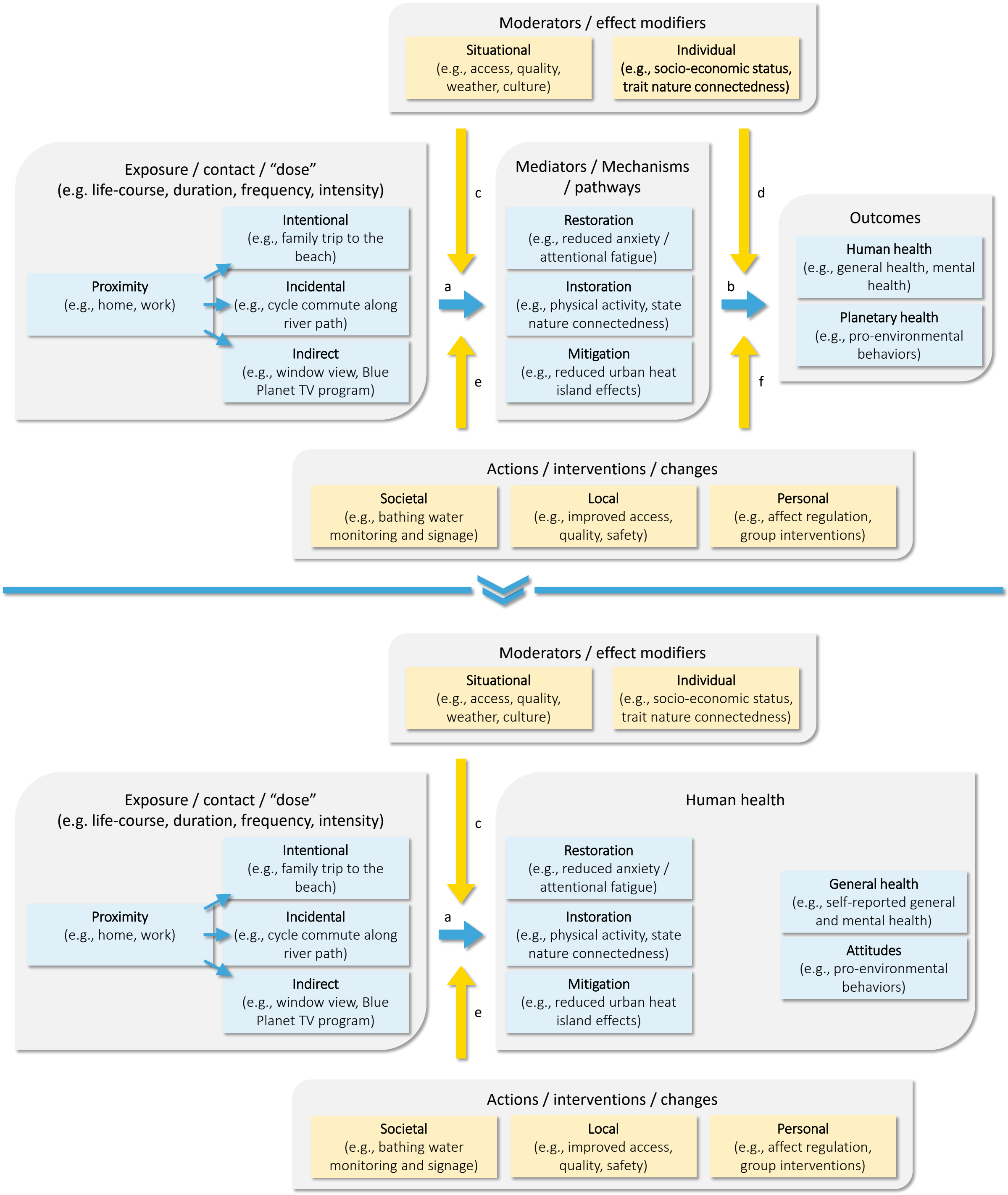


Figure 40: The proposal to merge mediators and outcomes to human health in the framework of White et al. (2020) and to change the 'planetary health' label to 'attitudes'.

5.3. Science-policy linkage

This emerging research topic is highly dependent on policy-makers' decisions with regard to the coastal experience. In the past, several changes have occurred with regard to the coastal experience. For example, in 2020, during the global corona crisis, the government set restrictions on travelling. This enabled the investigation of the importance of the coast for stress, worry, boredom, and other aspects of mental health for coastal residents who still had access to the coast (Severin et al., 2021). Another example is about the many blue transitions along the coast in Belgium that have had an impact on the visitors' and residents' experiences and attitudes. More specifically, dunes have been placed on the beach in front of the dike to safeguard the seaside resorts against storms and flooding, but these dunes limit people's views of the sea; offshore wind farms have made the horizon have an urban appearance instead of a natural one; and the constant battle against the transport of sand makes that bulldozers and excavators disturb the landscape, generate noise, and impact the experience. The BlueBALANCE project in Belgium from 2022 to 2025 investigates the mixed opinions and attitudes about such issues and how to communicate about them to prevent public resistance. Thus, scientists and policy-makers concerned with the topic should adapt the research landscape to the shifts in the coastal experience happening now and potentially in the future. Therefore, socio-cultural developments with respect to the coast should be monitored in order to identify and investigate the topics of opportunity and of most urgency.

As a last discussion point, it seems relevant to note that it has proven to be very difficult to communicate about the topic of this dissertation to policy-makers when the specific approach to health is not adopted. More specifically, in March 2024, an attempt was made to communicate the importance and current state-of-the-art about the holistic 'ocean and human health' approach to policy makers, but several struggles were encountered. The first struggle was defining the boundaries of the topic. Restricting the topic to matters concerning 'blue gym' (Depledge & Bird, 2009; Fleming et al., 2014; White, Pahl, et al., 2016) was one possibility, but so were defining the topic as 'everything in the world' (Borja et al., 2020; Fleming et al., 2019, 2021) and all scales in between. Another struggle was to pinpoint the suggested policy-actions. At this stage of the OHH research, it seemed impossible to define clear actions or considerations that we, as scientists, would like policy-makers to make, because the entity of the research was too broad and not clearly different from the underlying motivations, and there was simply not enough evidence to support actions. Furthermore, it seemed that many of issues with regard to OHH are already being addressed by different directives and strategic plans (e.g., 'Vitamin Sea' as part of the Strategic policy plan for the coast from 2024 to 2030; Westtoer & Toerisme Vlaanderen, 2024). A last struggle was identifying who or what political authorities to address. Even if the topic would have been restricted to the effects of the coast on the state and abilities of human beings, such as in this dissertation, then the topic is still relevant for the authorities concerned with health care, tourism, the environment, and socio-economic development (Coudenys et al., 2023; Degraer et al., 2023; Vandaele et al., 2023). Each authority is restricted to its own area of influence, and for an effective communication, each authority would have been needed to be informed by a tailored document. Given these struggles, perhaps the best action that scientists can take is to adopt the specific approach to health when communicating the topic to policy-makers and other stakeholders. At the current stage, the results of this dissertation are mainly inspirational, and it seems to be the right time to raise the awareness among policy-makers and other stakeholders about the importance of further investigating psychological, physiological, and social phenomena at the coast for fostering human health and sustainable transitions. However, at the current stage, it would not be appropriate to suggest actions for policy-makers or other stakeholders to take, besides funding follow-up research, because the evidence about the beneficial effects of the coast on human health is still too scarce.

General conclusion

Before the initiation of this doctoral research, many studies and narratives hinted to the benefits of the coast for health. However, there was still a knowledge void about the actual effects of exposure to the coast on human health, and particularly on mental health (Chapter I). Therefore, the general aims of this doctoral research were to gain evidence and to increase our understanding about the effects of coastal environments on human health (overarching research question A and B.1 of the SOPHIE's SRA; H2020 SOPHIE Consortium, 2020; Figure 5). The aims were tackled by providing evidence for the conceptualized pathways in the framework of White et al. (2020; Figure 4). Four empirical studies and data-descriptor highlighted pivotal psychological, physiological, and social phenomena in Belgium (Figure 41). The knowledge gap remains large, and many new questions were identified for future fundamental and applied research.

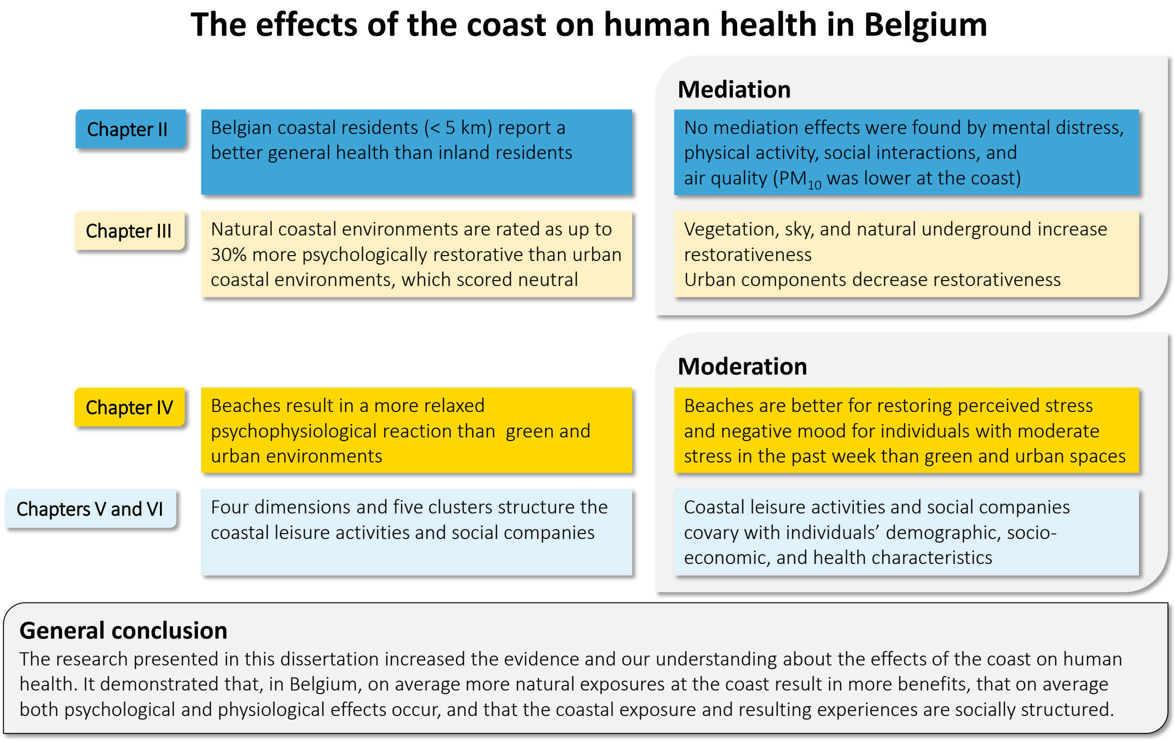


Figure 41: Overview of the results from the central chapters within this doctoral research. It depicts the linkages they make between exposure to the coast and human health and the mediating and moderating factors that were considered.

A first study in this dissertation showed that coastal residents (i.e., those living <5 km from the coast) report a better general health compared to individuals living further inland in Belgium (Chapter II). This justified exploring the effects of the coast further. This study also showed that the air quality (i.e., PM_{10} concentrations) was lower at the coast, but that coastal residents do not report a different level of mental distress, physical activity, or appreciation of their social interactions. However, in the meantime, external research showed that these mediators do explain the better self-reported general health of coastal residents when considering citizens' coastal visit frequency (Elliott et al., 2023).

A second study in this dissertation showed that students perceive natural coastal environments (i.e., beaches, salt marshes, and dunes) to be psychologically restorative, while urban coastal environments (i.e., seaside resorts, dikes, and harbors) as neutral (Chapter III). Since many previous studies showed that non-coastal natural environments are generally more restorative than urban ones, it seemed safe to conclude that on average also natural environments at the coast are more beneficial for mental health than urban ones.

A third study demonstrated that the breathing rate and sympathetic nervous system relaxed more in response to virtual beaches than to virtual inland green and urban environments (Chapter IV). This provided the first objective evidence about the psycho-physiologically restorative effects of the coast without the interference of physical activity. The parasympathetic nervous system, blood pressure and heart rate were not found to be affected differently by beaches. The measured changes in mood and perceived stress also suggested that beaches would be more restorative than green and urban environments for individuals who had a moderate stress in the past week.

Next, an openly available dataset based on a survey about the coastal visits and geo-demographic, socio-economic, and health characteristics of a representative Flemish sample (N = 1939) was described (Chapter V). The univariate descriptions showed that 67% of the respondents visited the coast in the previous year, and that many health-enhancing experiences (e.g., feeling relaxed) are gained often by most people (Chapter V). Those and many other interesting univariate trends in the data were presented in a data descriptor along with the quality and applicability of the data.

A fourth and last study mapped the social structuring of the activities performed at the coast and the social company with which they happen (Chapter VI). Four structuring dimensions were identified and five clusters of individuals with a similar coastal visit profile were revealed. These dimensions and clusters distinguished individuals on the basis of their coastal visit frequency, visited environment, social company, and reason for visiting. These visit characteristics were associated with the frequency, season, and types of visits typically made, the experiences gained, and the geo-demographic, socio-economic, and health situation of the individuals. As such, important insights were gained about the social differences in terms of exposure and experienced effects.

The research presented in this dissertation contributes to providing evidence for the conceptual framework described by White et al. (2020; Figure 38), and to answering to the research questions A and B.1 put forward by SOPHIE's SRA (H2020 SOPHIE Consortium, 2020; Chapter VII). Future research should primarily identify dose-response relationships and how the coasts acts on bio-psycho-social resilience. Future research should also target how the knowledge being acquired can be implemented in the health care sector (e.g., what best practices are for blue social prescribing), what the economic consequences are of the coast's benefits, and how ocean literacy can nurture a culture of care for a more sustainable coastal tourism. A 'specific approach to health' was conceptualized to clearly define the interpretation of 'health' and 'human health', to set clear boundaries on what the topic is about and not about, to communicate in a clear and unambiguous manner about the results and underlying motivations to scientists, policy-makers, and other stakeholders, and to help shape the future of this research topic. In conclusion, this dissertation led to crucial insights about the effects of different types of exposure to the coast on different health outcomes and the social structuring thereof. Continuing research on the psychological, physiological, and social phenomena at the coast may pose many benefits for society and the environment in the future.

Curriculum vitae

Personalia

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Professional experience

2019 – 2024	Doctoral researcher at Flanders Marine Institute (Research Department) and Ghent University (Department of Public health and Primary Care, Department of Sociology) on *"The coast and human health: an analysis of psychological, physiological, and social phenomena"* for achieving the title "Doctor of Health Sciences and of Sociology"
2018 – 2019	Science Officer at Flanders Marine Institute (Research Department)
2018	Job student at Ghent University (Marine Biology Research Group
2018	Internship at Flanders Marine Institute (Research Department)

Education

2019 – 2024	Doctoral Schools Training Program
2016 – 2018	Master of Science in Biology at UGent (Ghent, Belgium) – great distinction
2013 – 2016	Bachelor of Science in Biology at UGent (Ghent, Belgium) – distinction
2007 – 2013	Secondary school in Sciences (6h/w mathematics) at Sint-Jozefsinstituut Scholengroep Sint-Rembert (Torhout, Belgium)

Scientific A1 publications

1. **Hooyberg, A.**, Roose, H., Lonneville, B., De Henauw, S., Michels, N., Everaert, G. (2024). Survey data linking coastal visit behaviours to socio-demographic and health profiles. Sci. Data 11, 315. https://doi.org/10.1038/s41597-024-03161-y
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Published data

1. **Hooyberg, A.**, Michels, N., Roose, H., Everaert, G., Mokas, I., Malina, R., Vanderhasselt, M.A., De Henauw, S. (2024). Pseudonymized data and data analysis for 'The psychophysiological reactivity to beaches vs. to green and urban environments: insights from a virtual reality experiment'. Flanders Marine Institute and Ghent University. Marine Data Archive. https://marineinfo.org/id/dataset/8575
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1. **Hooyberg, A.**, Everaert G., Michels N., Roose H., De Henauw S., Vanderhasselt, M.-A., Allaert, J., Malina R., Mokas I., Janssen C., Asselman J. (2023). The psychophysiology of walking. https://osf.io/kzq2e/

Grants and Awards

1. Dr. Edouard Delcroix Incentive Award (2023; € 2500) for "Evidence for the health benefits of the Belgian coast: Psycho-physiological mechanisms and environment- and person-specific influential factors" by HYDRO vzw and Flanders Marine Institute vzw. https://www.vliz.be/en/imis?module=ref&refid=383592
2. Brilliant Marine Research Idea grant (2021; € 5000) for "The Nexus10 MKII for holistic insights in the physiological drivers behind mental health restoration from virtual coastal landscapes" by The Sea as Good Cause (Flanders Marine Insitute). https://www.vliz.be/en/imis?module=ref&refid=354455
3. Meet The PhD Jury grant (2024; € 1200) for "Green meets blue: international state-of-the-art on how outdoor environments influence human health" by Ghent University Doctoral School.

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1. **Hooyberg, A.** (2018). Temporal and spatial effects of offshore wind farms on the sediment and macrobenthos in the Belgian Part of the North Sea. MSc Thesis. Ghent University, Biology Department, Marine Biology Research Group: Ghent. 51 pp

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2. **Hooyberg, A.**, Roose, H., Lonneville, B., De Henauw, S., Michels, N., Everaert, G. (2024). The social structuring of recreational visits to the Belgian coast in 2022, in: Mees, J. et al. Book of abstracts – VLIZ Marine Science Day, 6 March 2024, Oostende. VLIZ Special Publication, 91: pp. 78
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14. **Hooyberg, A.**, Piasecka, M., Michels, N., Roose, H., De Henauw, S., Vandegehuchte, M., Everaert, G. (2020). Psychological restoration capacity of coastal environments and attributes by picture assessment, in: Mees, J. et al. Book of abstracts – VLIZ Marine Science Day. Oostende, Belgium, 18 March 2020. VLIZ Special Publication, 84: pp. 58.
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European Marine Biology Symposium. Oostende, Belgium, 17-21 September 2018. VLIZ Special Publication, 82: pp. 43.

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1. Kinet, J. (2023). Myth or fact: Does a coastal walk reduce stress? A physiological study with wearable technology. MSc Thesis. [Ghent University]. https://lib.ugent.be/catalog/rug01:003146525
2. Debra, G., & Mattheeuws, L. (2021). Do plants stimulate a healthy food choice: A photo experiment on how exposure to indoor green plants stimulates food wanting, stress, and mood [Ghent University]. https://lib.ugent.be/catalog/rug01:003008494
3. Wouters, S., & Robbe, M. (2022). A virtual visit to the coast: the influence on our physiological stress reactions - a quantitative, interventional study [Ghent University and Flanders Marine Institute]. https://lib.ugent.be/catalog/rug01:003060240
4. Schoutteten, L., & Geeraerts, E. (2022). Eenvirtuele uitstap naar de kust: een onderzoek naar de invloed van de kust op stress, gemoed, werkgeheugen en aandacht [Ghent University and Flanders Marine Institute]. https://lib.ugent.be/catalog/rug01:003060219
5. Van Den Berg, L. (2022). Effect van natuurintegratie: een interventie op stress en emoties, cognitief functioneren en voedselvoorkeur bij werknemers met een bureaufunctie. [Ghent University]. https://lib.ugent.be/catalog/rug01:003117113

Courses followed

1. Grow to Lead (2024). Organized by Doctoral Schools (Ghent University)
2. Grant-writing skills: the art of persuasion, with focus on the FWO Junior/Senior Postdoc Fellowships (2024). Organized by Doctoral Schools (Ghent University)
3. The mental reset (2023). Organized by Flanders Marine Institute
4. Measuring and analysing the peripheral psychophysiology of emotions and stress in children and adolescents (2022). Organized by Ghent University
5. The road to reliable and valid psychophysiological measurements and analyses: a practical course (Cortisol and alpha-amylase) (2022). Organized by Doctoral Schools (Ghent University)
6. Nature, health, and well-being (2022). Organized by European Centre For Environment And Human Health (ECEHH)
7. Project management (2022). Organized by Doctoral Schools (Ghent University)
8. Being interviewed (2022). Organized by Kenniscentrum Gezondheidszorg Gent
9. Structural Equation Modelling with lavaan in R (2021). Organized by Datacamp
10. Advanced Academic English: Writing Skills (Life Sciences & Medicine) (2021). Organized by Doctoral Schools (Ghent University)
11. Resilience in times of corona (2021). Organized by Trustpunt University of Ghent
12. Research, Resilience, and Zen (2021). Organized by Doctoral Schools (Ghent University)
13. Resilience at work (2021). Organized by Ghent University

14. Efficient mailing (2021). Organized by Flanders Marine Institute
15. Everybody coach (2021). Organized by Flanders Marine Institute
16. Advanced Academic English: Conference Skills - English Proficiency for Presentations (2021). Organized by Doctoral Schools (Ghent University)
17. Advanced Academic English: Conference Skills - Academic Posters (2021). Organized by Doctoral Schools (Ghent University)
18. Advanced Academic English: Conference Skills - Effective Slide Design (2021). Organized by Doctoral Schools (Ghent University)
19. Advanced Academic English: Conference Skills - Presentation Skills in English (2021). Organized by Doctoral Schools (Ghent University)
20. The road to reliable and valid psychophysiological measurements and analyses: a practical course (Heart Rate Variability and Skin Conductance) (2020). Organized by Doctoral Schools (Ghent University)
21. The road to reliable and valid psychophysiological measurements and analyses II: a practical course (Electrocardiography and Pupillometry) (2020). Organized by Doctoral Schools (Ghent University)
22. Research Data Management in Life Sciences (2020). Organized by Doctoral Schools (Ghent University), Flemish Institute for Biotechnology (VIB), ELIXIR Belgium, Interreg Vlaanderen-Nederland
23. Efficiency at work (2020). Organized by Department of Public Health and Primary Care (Ghent University)
24. How to present online with impact (2020). Organized by Flanders Marine Institute
25. How to present your research with impact (2020). Organized by Kenniscentrum Gezondheidszorg Gent
26. Peer review (2019). Organized by Conference ISEE2019

Supplementary information

1. Supplementary information for Chapter II

1.1. Tables

Table S 1: Overview of the health variables, proximity to the coast and the 12 covariables considered for control in the regression models.

	N (NA's excluded)	Based on question(s)/source	Reported answers	Value after manipulation	Year(s) questioned
Health					
General health	40970	How is your health in general?	Very bad, bad, fair, good, very good	1 - 5	1997, 2001, 2004, 2008, 2013
Residential proximity to the coast					
Proximity to the coast	60939	Town of residence based on National Register	390 municipalities in Belgium	0 - 310 km	1997, 2001, 2004, 2008, 2013
Covariables					
Age	60939	What is your age?	0 - 105 year	0-20, 21-45, 46-65, 65+	1997, 2001, 2004, 2008, 2013
Gender	60939	What is your gender?	Male, Female	Male, Female	1997, 2001, 2004, 2008, 2013
Having a chronic disease	32657	Do you suffer from (have) any chronic (long-standing) illness or condition (health problem)?	Yes, No	Yes, No	2001, 2004, 2008, 2013
BMI	45268	From length and weight of the respondents: How tall are you without shoes? How much do you weigh without clothes and shoes?	0 - 529	Normal weight, Underweight, Pre-obesity, Obesity class I, Obesity class II, Obesity class III	1997, 2001, 2004, 2008, 2013
Employment status	43569	Do you have at this moment a paid job, even if it is temporarily interrupted?	Yes, No	Yes, No	1997, 2001, 2004, 2008, 2013
Income	52468	Income of respondents compared to income distribution of Belgian population	Quintile 1, Quintile 2, Quintile 3, Quintile 4, Quintile 5	Quintile 1, Quintile 2, Quintile 3, Quintile 4, Quintile 5	1997, 2001, 2004, 2008, 2013
Smoking status	36963	Do you smoke at all nowadays?	Yes, daily, Yes, occasionally, Not at all	Non-smoker, occasional smoker, daily smoker	1997, 2001, 2004, 2008, 2013
Urbanization level	60939	Personal observations from HIS team based on criteria from Merenne et al 1997	Urban, sub-urban, rural	Urban, sub-urban, rural	1997, 2001, 2004, 2008, 2013
Green space ratio	54595	Statbel.be	6.4 % - 92.2 %	< 10 %, 10-20 %, 20-30 %, 30-40 %, 40-50 %, 50-60 %, 60-70 %, 70-80 %, 80-90 %, 90-100%	1997, 2001, 2004, 2008, 2013
Blue space ratio	55668	Statbel.be	0.0 % - 6.6 %	< 0.25 %, 0.25-0.5 %, 0.5-0.75 %, 0.75-1 %, 1-1.25%, 1.25-	1997, 2001, 2004, 2008, 2013

				1.5 %, 1.5-1.75 %, 1.75-2%, > 2%	
Season	60939	Date of taking the survey	For the 1997 survey: 01.01.1997 – 31.12.1997 For the 2001 survey: 01.01.2001 – 31.12.2001 For the 2004 survey: 01.02.2004 – 31.01.2005 For the 2008 survey: 15.05.2008 – 30.06.2009 For the 2013 survey: 01.01.2013 – 31.12.2013	Winter, spring, summer, fall	1997, 2001, 2004, 2008, 2013
Year	60939	Date of taking the survey	For the 1997 survey: 01.01.1997 – 31.12.1997 For the 2001 survey: 01.01.2001 – 31.12.2001 For the 2004 survey: 01.02.2004 – 31.01.2005 For the 2008 survey: 15.05.2008 – 30.06.2009 For the 2013 survey: 01.01.2013 – 31.12.2013	1997, 2001, 2004, 2008, 2013	1997, 2001, 2004, 2008, 2013
Hypothesized mechanisms					
Mental health	40535	All 12 items of the GHQ-12	More so than usual, same as usual, less than usual, much less than usual	0 - 12	1997, 2001, 2004, 2008, 2013
Physical activity	22451	6 questions related to how many days of vigorous, moderate and walking activities and the usual time spent performing these activities	0 - 25704 MET-min/week	< 250 MET-min/week, 250-1250 MET-min/week, 1250-2500 MET-min/week, 2500-3500 MET-min/week, > 3500 MET-min/week	2001, 2004, 2008, 2013
Appreciation of social interactions	40983	How would you judge your social contacts?	Really satisfying, rather satisfying, rather unsatisfying, really unsatisfying	0 (really unsatisfying) – 3 (really satisfying)	1997, 2001, 2004, 2008, 2013
Air quality: PM_{10} concentration	60939	irCELine	8.3 µg/m³- 45.0 µg/m³	< 10 µg/m³, 10-20 µg/m³, 20-30 µg/m³, 30-40 µg/m³, 40-50 µg/m³	1997, 2001, 2004, 2008, 2013

1.2. Figures

Model diagnostics revealed a linear distribution of the data with homogeneous variances (no heteroscedasticity) and the absence of outliers (Figure S 1, Figure S 2, Figure S 3, Figure S 4)). All models violate the assumption of normality.

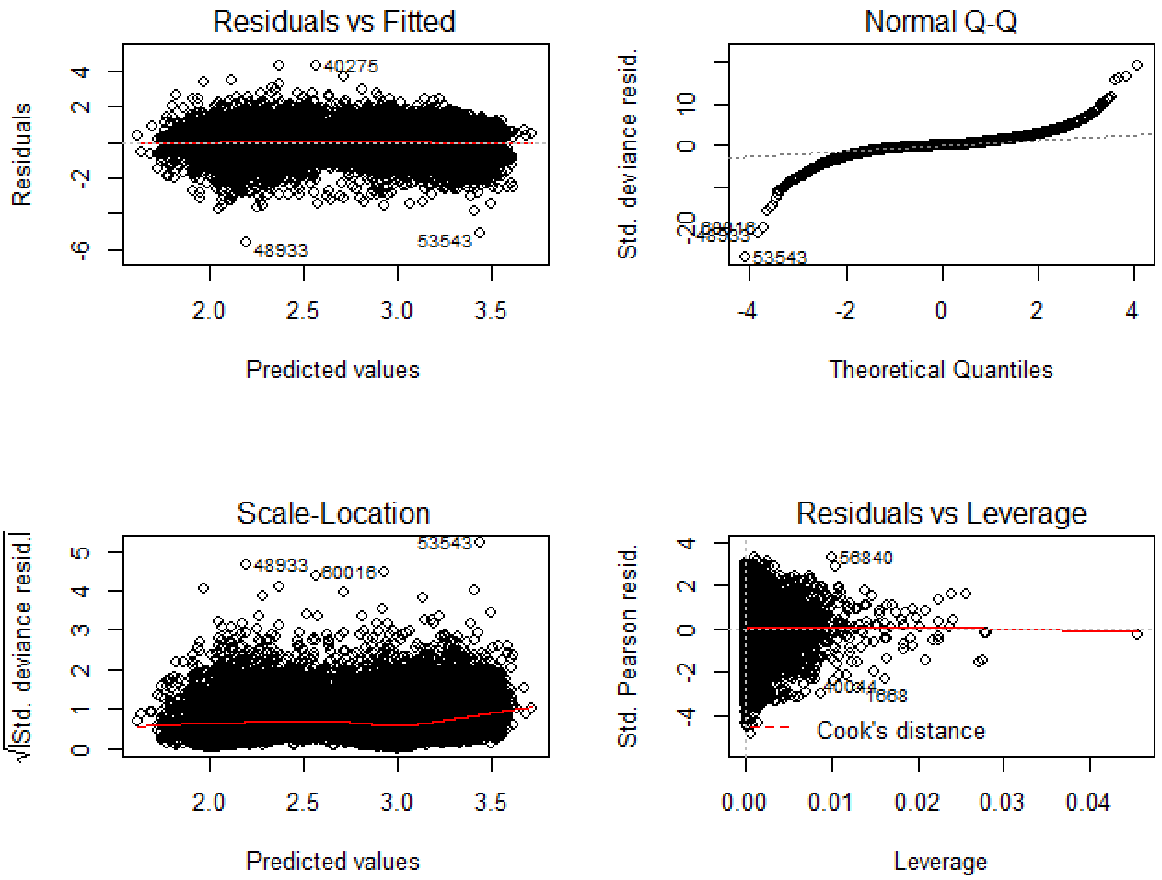

Figure S 1: Model diagnostics for comparing general health between coastal and inland populations. Top-left: the horizontal distribution of the residuals vs the fitted values indicate linear dependency; top-right: deviation at the ends of the normal Q-Q line indicates deviation from normality; bottom-left: Horizontal distribution of the variance of the residuals indicates homoscedasticity; bottom-right: Residuals vs the leverage indicates the absence of outliers.

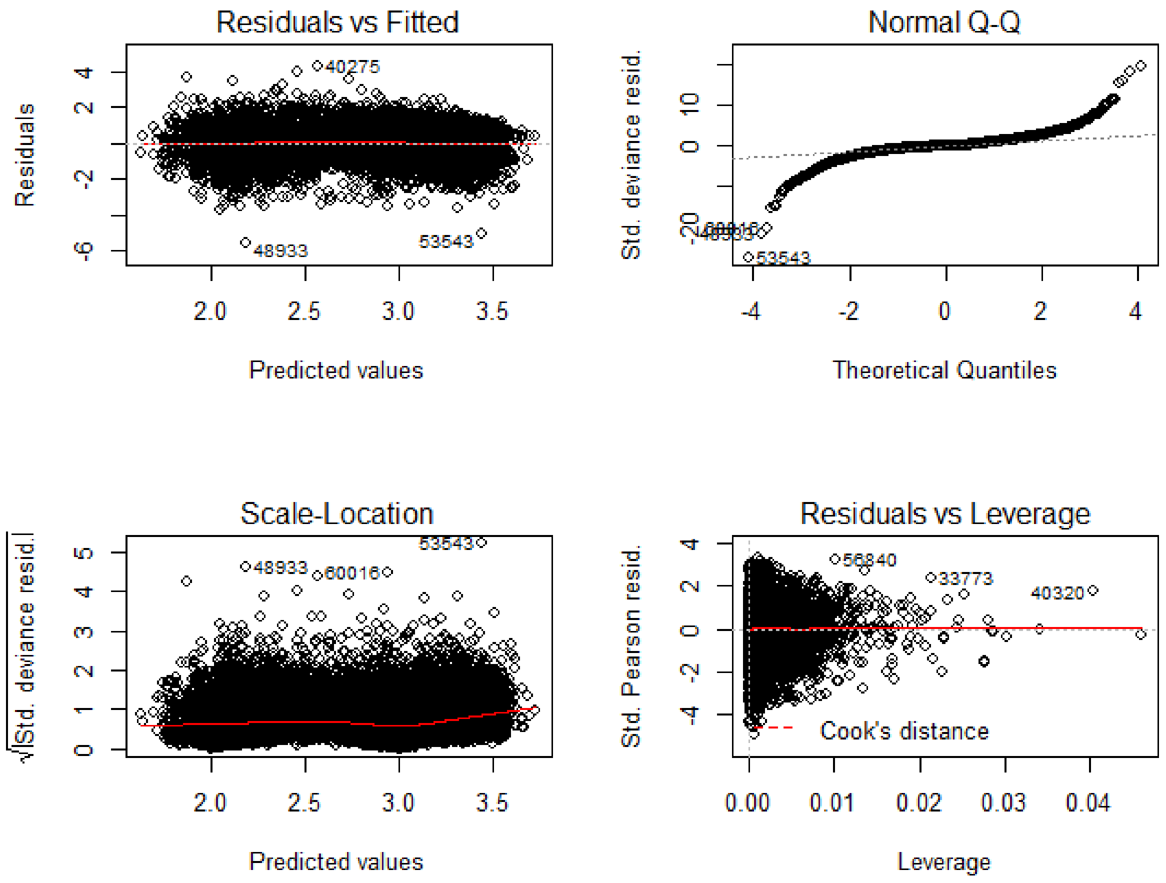

Figure S 2: Model diagnostics for the model comparing general health between eight populations with different proximity to the coast. Top-left: the horizontal distribution of the residuals vs the fitted values indicate linear dependency; top-right: deviation at the ends of the normal Q-Q line indicates deviation from normality; bottom-left: Horizontal distribution of the variance of the residuals indicates homoscedasticity; bottom-right: Residuals vs the leverage indicates the absence of outliers.

The modelling procedure inherently resulted in data reduction that was used in the model, since added variables contained missing values. This could lead to biased results from only including a particular part of the population. However, Figure S3 and Table S2 show that the data used in the entire survey compared to the data in the models had consistent age, sex ratio and income over all different categories of proximity to the coast, and that demographic characteristics also remained similar under the data-reduction.

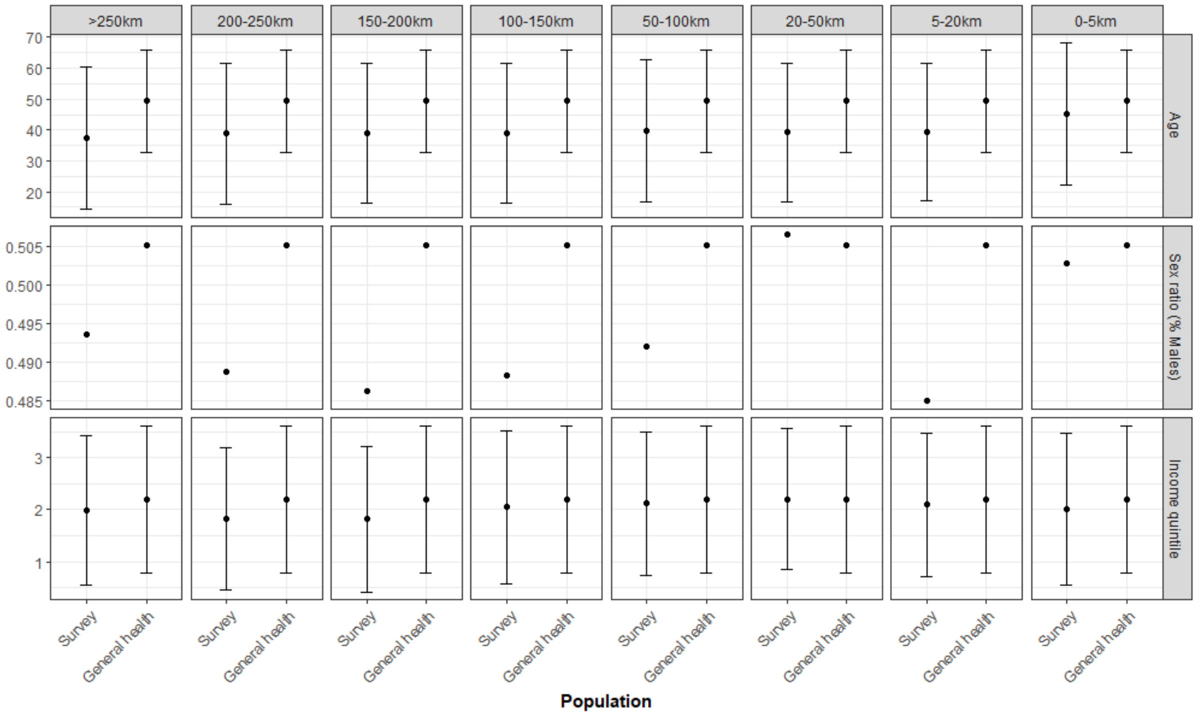

Figure S 3: Overview of the data that was available in the entire survey ('Survey' on x-axis) and the subset of the data that was used during modelling ('General health' on x-axis). Columns further subdivide the data according to different categories of proximity to the coast and rows indicate the age, sex ratio and income of the participants.

Table S 2: Overview of demographic parameters in all survey data, and of the data used during analyses. 'Data models' represents the models used to assess the total general health – residential proximity to the coast relationships, while 'Data mediation' refers to the models used for the mediation analyses used to investigate the indirect effects of the four hypothesized mechanisms.

	All data (N = 60,939) N = 57,360		**Data models** N = 23,624		**Data mediation** N = 15,418	
	Mean (1st Q, 3rd Q))/%	**Weighted mean (1st Q, 3rd Q))/%**	**Mean (1st Q, 3rd Q))/%**	**Weighted mean (1st Q, 3rd Q))/%**	**Mean (1st Q, 3rd Q))/%**	**Weighted mean (1st Q, 3rd Q))/%**
Mean age (years)	42.7 (24, 61)	39.263 (21, 56)	51.67 (37, 65)	49.378 (36, 62)	51.450 (37, 65)	49.342 (36,62)
Gender ratio (% males)	0.478	0.490	0.488	0.500	0.491	0.505
Ratio having a chronic disease (% no)	0.954	0.601	0.681	0.708	0.674	0.702
Mean BMI	25.129 (21.936, 27.472)	25.116 (21.967, 27.459)	25.379 (22.222, 27.739)	25.385 (22.266, 27.732)	25.344 (22.204, 27.732)	25.346 (22.222, 27.682)
Ratio employed (% yes)	0.568	0.523	0.508	0.558	0.518	0.564
Mean income (Q1, Q2, Q3, Q4, Q5)	1.91 (1, 3)	2.01 (1, 3)	2.062 (1, 3)	2.135 (1, 3)	2.124 (1, 3)	2.196 (1, 3)
Smoking ratio (% non-smoker)	0.996	0.633	0.678	0.672	0.698	0.693
Urbanization ratio (% urban)	0.525	0.449	0.444	0.411	0.466	0.422
Mean neighborhood green space	0.361 (0.209, 0.468)	0.340 (0.218, 0.430)	0.369 (0.218, 0.487)	0.340 (0.217, 0.430)	0.365 (0.215, 0.485)	0.338 (0.215, 0.430)
Mean neighborhood blue space	0.005 (0.001, 0.007)	0.006 (0.001, 0.007)	0.005 (0.001, 0.007)	0.006 (0.001, 0.008)	0.005 (0.001, 0.007)	0.006 (0.001, 0.007)

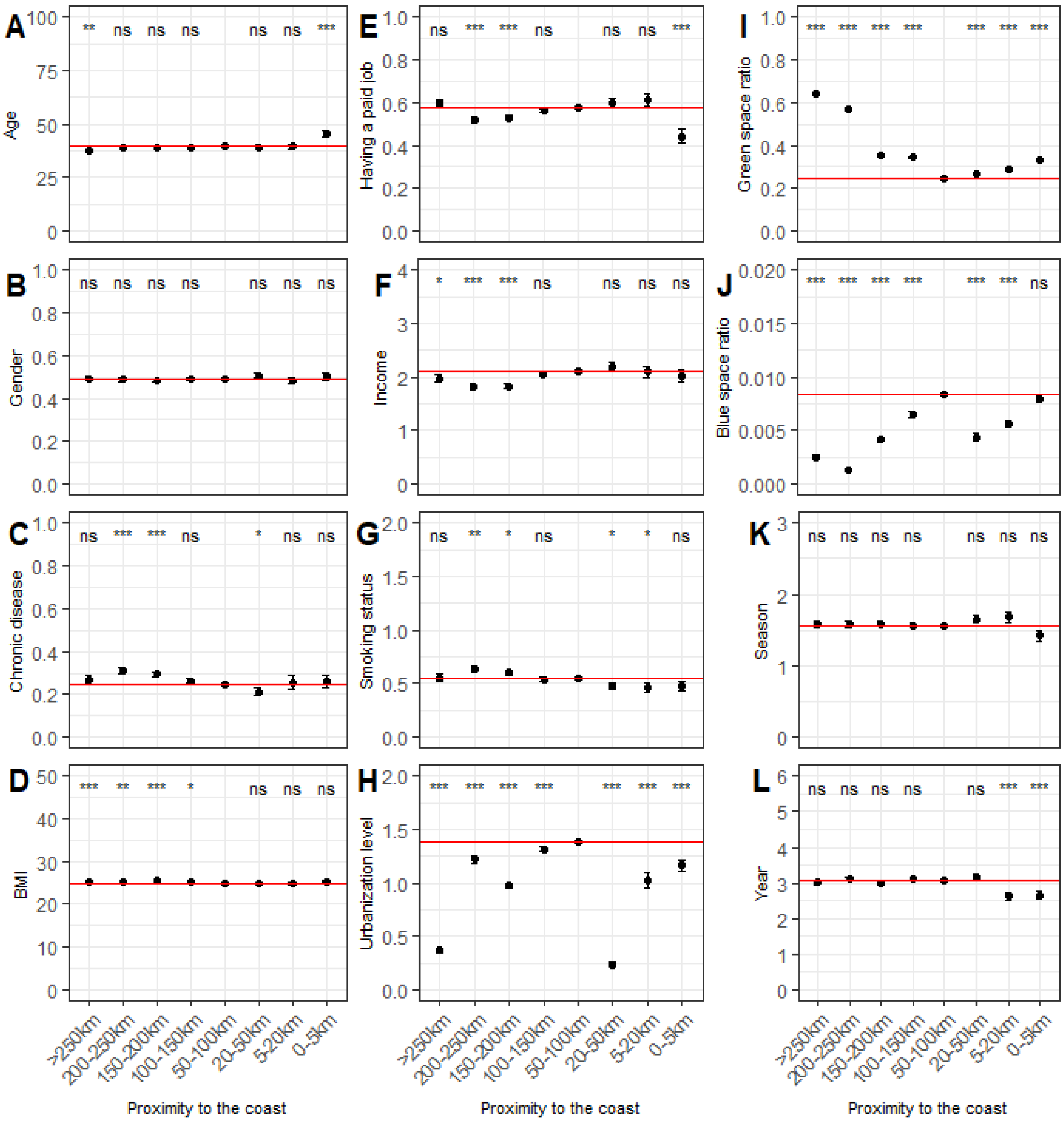

Figure S 4: Visualization of predicted output using linear regression models between each of the 12 covariables (A-L) and proximity to the coast (sole predictor). All categorical variables were numerically transformed.

2. Supplementary information for Chapter III

2.1. Methods

2.1.1. Covariates

Table S 3: Tabulation of all covariates included in this study, with the reasons for inclusion and characteristics of the data used.

	Covariate	Hypothesis for inclusion	Type of data	Details	Factor levels (categorical) or range (numerical)
Demographic and lifestyle-related	Age	Age may partly determine the restoration differences between landscapes, although still unclear (Ohly et al., 2016).	Single-item	Wat is your age?	18-21y, 21-24y, >24y
	Gender	Gender may partly determine the restoration differences between landscapes, although still unclear (Ohly et al., 2016).	Single-item	Wat is your gender?	male, female, or other
	Socio-economic status	Lower socio-economic is associated with better health in close proximity to the coast (Wheeler et al., 2012).	Single-item	How do you rate your socio-economic situation compared to people of similar age?	very good, good, neutral, bad, very bad categorized into very good, good, or neutral/bad/very bad
	BMI	BMI can be associated with movement constraints in certain coastal landscapes, therefore constraining restoration in particular landscapes.	Single-item	What is your weight? What is your length?	BMI scores calculated from length and weight, then categorized into normal weight, underweight, pre-obesity, obesity class I,

					obesity class II, obesity class III
	Physical activity	Physical activity and a person’s condition may be associated with movement abilities in certain coastal landscapes, therefore constraining restoration in particular landscapes.	Derivative of a validated questionnaire	3-item questionnaire based on the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) using energy requirements defined in METs (multiples of the resting metabolic rate) in combination with the number of minutes per week that are spent walking (3.3 METs), performing moderate intensity activities (4.0 METs, e.g., cycling) and vigorous intensity activities (8.0 METs, e.g., running)	0 - ... METs/min.
	Diet	Diet proxies for a person's health behavior and health, although yet unclear (Michels et al., 2021).	Single-item	Wat is your diet?	various answers categorized into meat, no meat
	Dog ownership	Dog walking relates to spending time outdoors, and may have shaped a person's rating for specific landscapes (White et al., 2013).	Single-item	Do you have a dog at the moment?	yes, no
	Smoking status	Smoking has been related to diverse (mental) health-related outcomes (Bonnie et al., 2015) which may impact restoration in uncertain ways.	Single-item	Wat is your smoking status?	non-smoker, (formal) smoker
Environm ent-related	Associating the Belgian	Constrained restoration can mainly occur when a person is not 'away from everyday	Single-item	Do your school- or work-activities have something to do with the Belgian coast?	yes, no

coast with obligations	obligations' (Von Lindern et al., 2013).			
Number of visits to the Belgian coast in the past three months	One's familiarity with the Belgian coast can predict the ability to immerse in the landscape shown on the picture.	Single-item	How many times did you visit the Belgian coast in the past three months for leisure?	0 - ... times
Number of visits to the Belgian coast in the past year	One's familiarity with the Belgian coast can predict the ability to immerse in the landscape shown on the picture.	Single-item	How many times did you visit the Belgian coast in the past year for leisure?	0 - ... times
Number of visits to the Belgian coast per year as a kid	Nostalgic experiences in coastal environments are currently being investigated (Jarratt and Gammon, 2016; Severin et al., 2021).	Single-item	How many days on average per year did you visit the Belgian coast when you were less than 10 year?	0 - ... days per year
Residential coastal proximity	Residential coastal proximity is known to impact health, although the mechanisms are still unclear (Hooyberg et al., 2020).	Single-item	How far or how close is your home situated from the Belgian coast?	Less than 1 km, between 1 and 5 km, between 5 and 20 km, between 20 and 50 km, more than 50 km
Satisfaction to residential coastal proximity	A person's eagerness to be closer to the coast may be related to the restorative potential of certain coastal landscapes.	Single-item	Would you rather have the coast to be more or less accessible from your home location?	Rather have had the coast to be more accessible, just right, rather have had the coast to be less accessible
Near-home urbanization	A person's residential urban landscape may determine the restoration potential of other	Single-item	Is the landscape in a radius of 500 meters around your home rather ...?	urban, semi-urban, rural

	urban landscapes (e.g., at the coast).			
Near-home access to green spaces	A person's residential green exposure may determine the restoration potential of other green landscapes (e.g., at the coast).	Single-item	In the landscape in a radius of 500 meters around your home (including at home), how much access do you have to natural greenery, such as forests, parks, nature areas, or agricultural land?	a lot, moderate, little, no access
Near-home access to blue spaces	A person's residential blue exposure may determine the restoration potential of other blue landscapes (e.g., at the coast).	Single-item	In the landscape in a radius of 500 meters around your home (including at home), how much access do you have to natural water features such as ponds or rivers?	a lot, moderate, little, no access
Near-home air quality	Visitors' perception of air quality is known to affect the perceived restorativeness (Hipp and Ogunseitan, 2011).	Single-item	How healthy do you find the air around your home?	0 (very unhealthy) - 10 (very healthy) Likert-scale
Near-home noise levels	Noise sensitivity is known to moderate the effect of the landscape on perceived restoration (Ojala et al., 2019), so one can expect the same for perceived noise levels.	Single-item	How much noise disturbance do you have around your home?	0 (no disturbance) - 10 (a lot of disturbance) Likert-scale
Nature relatedness	Nature connectedness has been found to predict a person's well-being and mood (Mayer and Frantz, 2004; Whitburn et al., 2019).	Validated questionnaire	Nature Relatedness (NR) scale (Nisbet and Zelenski, 2013)	1 (low NR) - 5 (high NR)

	Coastal relatedness	Similar as nature relatedness, coastal relatedness may be closely linked to the perceived restoration potential of (some) coastal landscapes.	Derivative of a validate questionnaire	6-item Coastal Relatedness scale (derivative of NR)	1 (low CR) - 5 (high CR)
Health-related	Sleep quality	Sleep quality determines cognitive performance (Deak and Stickgold, 2010), and the amount of perceived restoration is dependent on the state cognitive resources (Kaplan, 1995). Furthermore, sleep can impact the perceived restoration of only some coastal landscapes.	Single-item	How many nights per week do you experience having trouble falling asleep or having unrestful sleep?	never, 1 x/week or less, 2-3 x/week, 4-5 x/week, 6-7 x/week
	Stress in the past month	In the context of exposure to natural settings, the stress recovery theory is complementary to the attention restoration theory in that both stress and cognitive resources are affected by nature and are inextricably linked to each other (Kaplan and Kaplan, 1989; Ulrich et al., 1991).	Validated questionnaire	10-item Perceived Stress Scale (PSS) (van der Ploeg, 2013)	0 (no stress) - 4 (maximal stress)
	Burnout score	Nature therapy can decrease the propensity for developing burnout (Stigsdotter et al., 2018), but effect sizes may depend on the type of (natural) landscape.	Validated questionnaire	33-item Burnout Assessment Tool (BAT) (Schaufeli et al., 2019)	1 (no burnout risk) - 5 (maximal burnout risk)

	Rumination	Rumination, as both a mediator between the effects of stress on health (Brosschot et al., 2006) and between the effects of nature on stress (Bratman et al., 2021) is a crucial potential confounder.	Validated questionnaire	13-item Perseverance Thinking Questionnaire - Trait version (PTQ-t) (Ehring et al., 2012)	0 (no rumination) - 60 (severe rumination)
	Sense of coherence	As a core construct of the salutogenesis theory (Mittelmark et al., 2017), the sense of coherence reflects a person's ability to use available resources (e.g., nature as a solution, cognitive resources) to combat stress and promote health, and is a complementary concept to restorative environments (von Lindern et al., 2017).	Validated questionnaire	13-item Sense of Coherence Scale (SOC) (Jellesma et al., 2006; Luyckx et al., 2012)	1 (no capacity to deal with stress) - 5 (high capacity to deal with stress)
	State stress	State stress right before the exposure can be a major determined of the perceived restoration of the scenes (Berto, 2014).	Single-item	On a scale from 0 to 10, rate how stressed you are at this moment.	0 (totally relax) - 10 (very stressed)
Other	Picture order	Fatigue-effects and learning-effects may influence the rating of picture through the process of the experiment.	Study design	/	1 - 94
	Period of sampling	Societal context changed drastically due to the COVID-19 pandemic and associated government regulations, including the ban for inland	Study design	/	Period 1, Period 2

	residents to visit the coast. This may influence how the participants perceived the coast and the different coastal landscapes.			
Momentary outside temperature	Weather is known to determine a person's willingness to go out, to for example visit the coast and benefit restoration (Elliott et al., 2019). The effect of temperature is not straightforward (Mullins and White, 2019).	Weather data at the moment of sampling	/	... °C
Momentary outside precipitation	Weather is known to determine a person's willingness to go out, to for example visit the coast and benefit restoration (Elliott et al., 2019). Precipitation can be especially impactful (White et al., 2014).	Weather data at the moment of sampling	/	0 - ... mm/h
Momentary outside wind	Weather is known to determine a person's willingness to go out, to for example visit the coast and benefit restoration (Elliott et al., 2019). Wind is generally stronger in coastal areas, and inland wind may reflect the propensity to prefer certain less windy coastal landscapes over more windy coastal areas.	Weather data at the moment of sampling	/	0 - ... bft
Momentary outside humidity	Weather is known to determine a person's willingness to go out, to for example visit the coast	Weather data at the moment of sampling	/	0 - 100 %

	and benefit restoration (Elliott et al., 2019). Humidity relates to precipitation and other weather phenomena.			

Table S 4: Cronbach-alpha calculation of all multi-item questionnaires assessed either as covariate.

Questionnaire	Item	Raw alpha	Standardized Alpha	Raw alpha if item is dropped	Standardized alpha if item is dropped
Stress in the past month	PSS.1.num	0.83	0.84	0.82	0.83
	PSS.2.num			0.80	0.80
	PSS.3.num			0.80	0.81
	PSS.4.num			0.82	0.82
	PSS.5.num			0.82	0.82
	PSS.6.num			0.82	0.83
	PSS.7.num			0.84	0.84
	PSS.8.num			0.81	0.81
	PSS.9.num			0.83	0.83
	PSS.10.num			0.81	0.82
Rumination	PTQt.1.num	0.92	0.92	0.91	0.91
	PTQt.2.num			0.91	0.91
	PTQt.3.num			0.91	0.91
	PTQt.4.num			0.91	0.91
	PTQt.5.num			0.91	0.91
	PTQt.6.num			0.91	0.91
	PTQt.7.num			0.91	0.91
	PTQt.8.num			0.91	0.91
	PTQt.9.num			0.91	0.91
	PTQt.10.num			0.91	0.91
	PTQt.11.num			0.91	0.91
	PTQt.12.num			0.92	0.92
	PTQt.13.num			0.91	0.91
	PTQt.14.num			0.92	0.91
	PTQt.15.num			0.91	0.91
Sense of coherence	SOC13.1.num	0.84	0.84	0.85	0.84
	SOC13.2.num			0.84	0.83
	SOC13.3.num			0.83	0.82
	SOC13.4.num			0.85	0.84
	SOC13.5.num			0.83	0.82
	SOC13.6.num			0.83	0.83

	SOC13.7.num			0.84	0.83
	SOC13.8.num			0.82	0.82
	SOC13.9.num			0.82	0.81
	SOC13.10.num			0.82	0.82
	SOC13.11.num			0.83	0.83
	SOC13.12.num			0.84	0.83
	SOC13.13.num			0.83	0.82
Nature relatedness	NR6.1.num	0.87	0.87	0.86	0.86
	NR6.2.num			0.87	0.87
	NR6.3.num			0.84	0.84
	NR6.4.num			0.83	0.83
	NR6.5.num			0.82	0.82
	NR6.6.num			0.83	0.83
Coastal relatedness	CR6.1.num	0.87	0.87	0.86	0.86
	CR6.2.num			0.88	0.88
	CR6.3.num			0.83	0.83
	CR6.4.num			0.83	0.83
	CR6.5.num			0.82	0.82
	CR6.6.num			0.86	0.85
Burnout score	BAT.1.num	0.92	0.92	0.92	0.92
	BAT.2.num			0.92	0.92
	BAT.3.num			0.92	0.92
	BAT.4.num			0.92	0.92
	BAT.5.num			0.92	0.92
	BAT.6.num			0.92	0.92
	BAT.7.num			0.92	0.92
	BAT.8.num			0.92	0.92
	BAT.9.num			0.92	0.92
	BAT.10.num			0.92	0.92
	BAT.11.num			0.92	0.92
	BAT.12.num			0.92	0.92
	BAT.13.num			0.92	0.92
	BAT.14.num			0.92	0.92
	BAT.15.num			0.92	0.92
	BAT.16.num			0.92	0.92

	BAT.17.num	0.92	0.92
	BAT.18.num	0.92	0.92
	BAT.19.num	0.92	0.92
	BAT.20.num	0.92	0.92
	BAT.21.num	0.92	0.92
	BAT.22.num	0.92	0.92
	BAT.23.num	0.92	0.92
	BAT.24.num	0.92	0.92
	BAT.25.num	0.92	0.92
	BAT.26.num	0.92	0.92
	BAT.27.num	0.92	0.93
	BAT.28.num	0.92	0.92
	BAT.29.num	0.92	0.92
	BAT.30.num	0.92	0.92
	BAT.31.num	0.92	0.92
	BAT.32.num	0.92	0.92

2.1.2. Picture-set assembly

Table S 5: Factors that were considered during the picture taking to ensure sharp, realistic, and representative pictures, and how these factors were accounted for.

Factors accounted for	How realized
Pictures must be representative for the landscape at the Belgian coast.	• Suitable locations were searched by scanning the Belgian coastal area on Google Maps. • Researchers investigated the area on-site for suitable frames that contained no abnormal, artistic, dramatic, or disturbing elements that would distract the participant from the overall scenery (e.g., youth playing in the foreground), and 'classic' views were photographed.
The landscape must be photographed from a realistic viewing angle.	• Pointing the camera in parallel with the most common walking direction or looking direction (depending of scene of interest) at the site. • Levelling and centering the horizon to the middle of the vertical axis of the frame. • Shooting from eye-level (between 1.50-1.80 cm height) with landscape orientation
Weather conditions must be uniform across pictures.	• Only take pictures in sunny and calm weather conditions with limited clouds and wind, without precipitation.
Shadows must be realistic, easily interpretable, and not hinting to what is happening outside the frame.	• Shadows of the researchers taking the pictures were avoided at all time. • Shadows of other elements (e.g., birds flying over) that could confuse the participants were also avoided to the degree possible. • Shadows of buildings were not deemed to be distracting or confusing
Shooting with a high-resolution camera and a camera lens, and with a focal length that represents the human viewing angle.	• Professional camera and lens setup: Nikon D850 (45.7 megapixels) + AF-S NIKKOR 24-120 mm f/4 ED VR @ 24 mm.
Shooting with camera settings that ensure sharpness throughout the depth-of-field present in the image.	• Shutter speed 1/50s or higher, aperture F13 or higher, and maximum ISO 800.

2.1.3. Picture components

Descriptive graphs

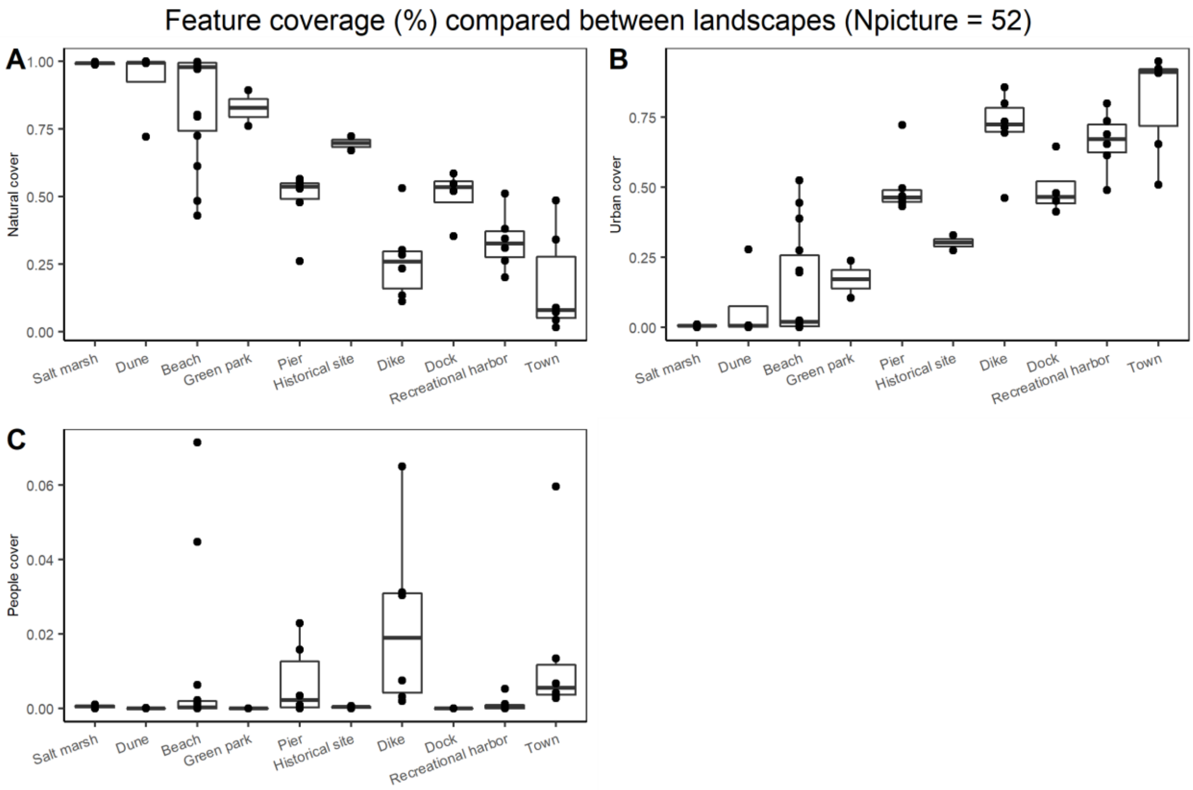

Figure S 5: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

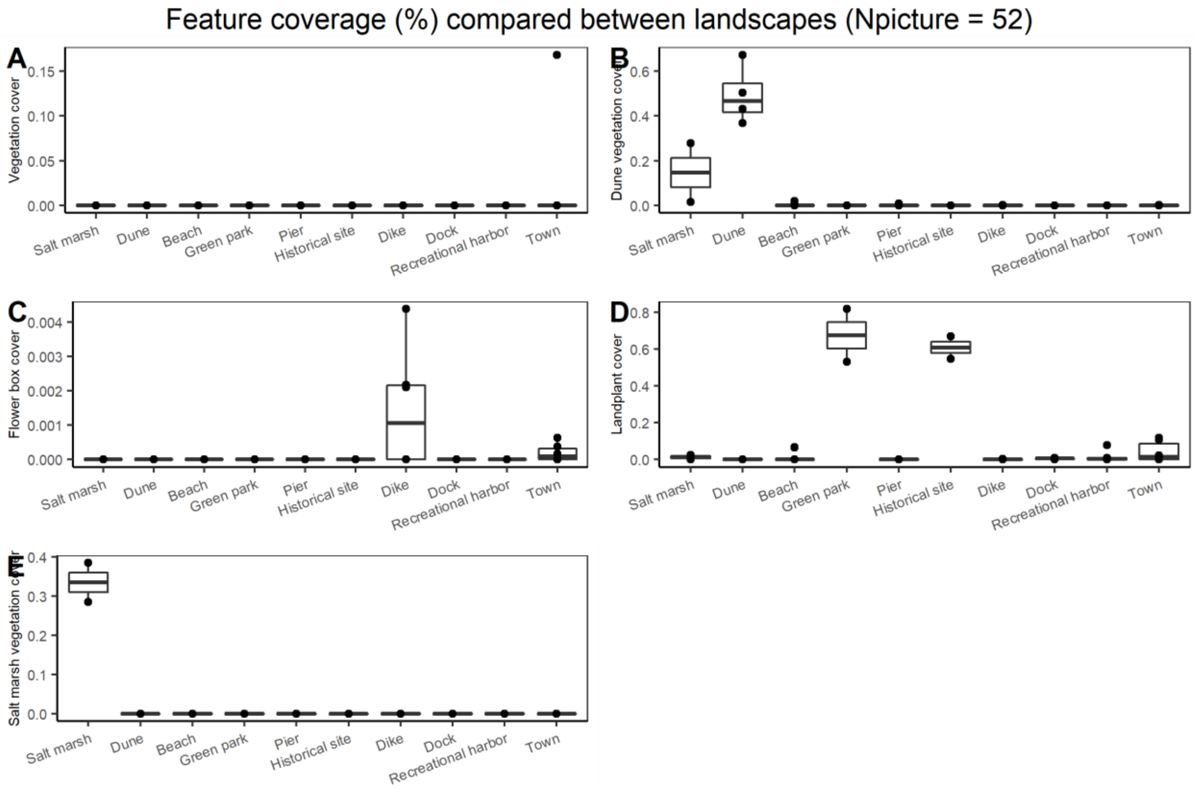

Figure S 6: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

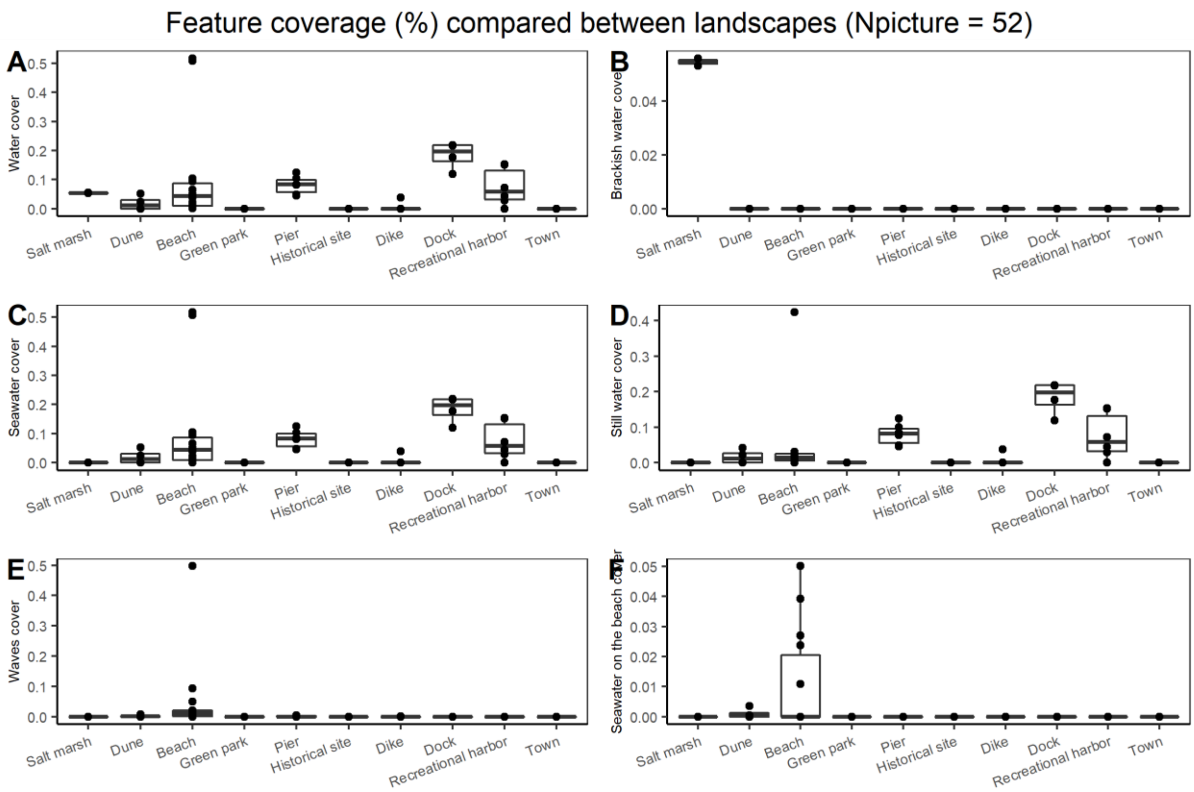

Figure S 7: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

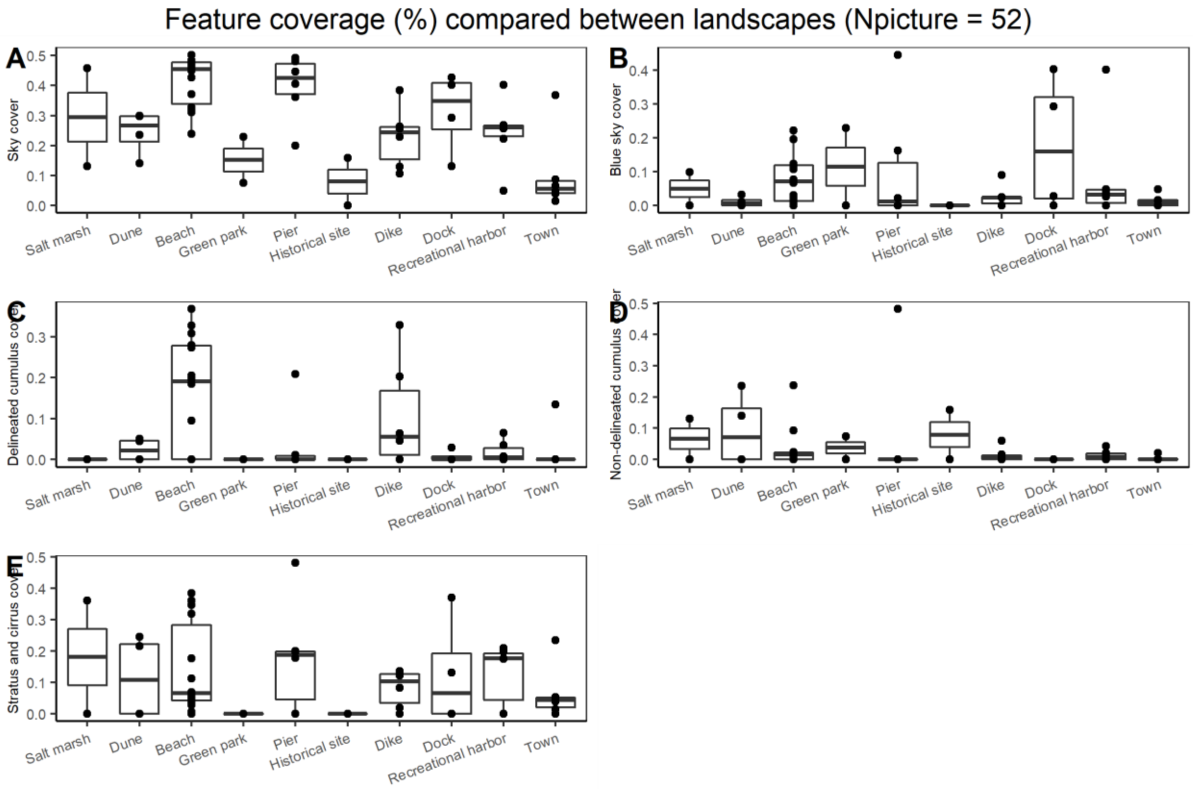

Figure S 8: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

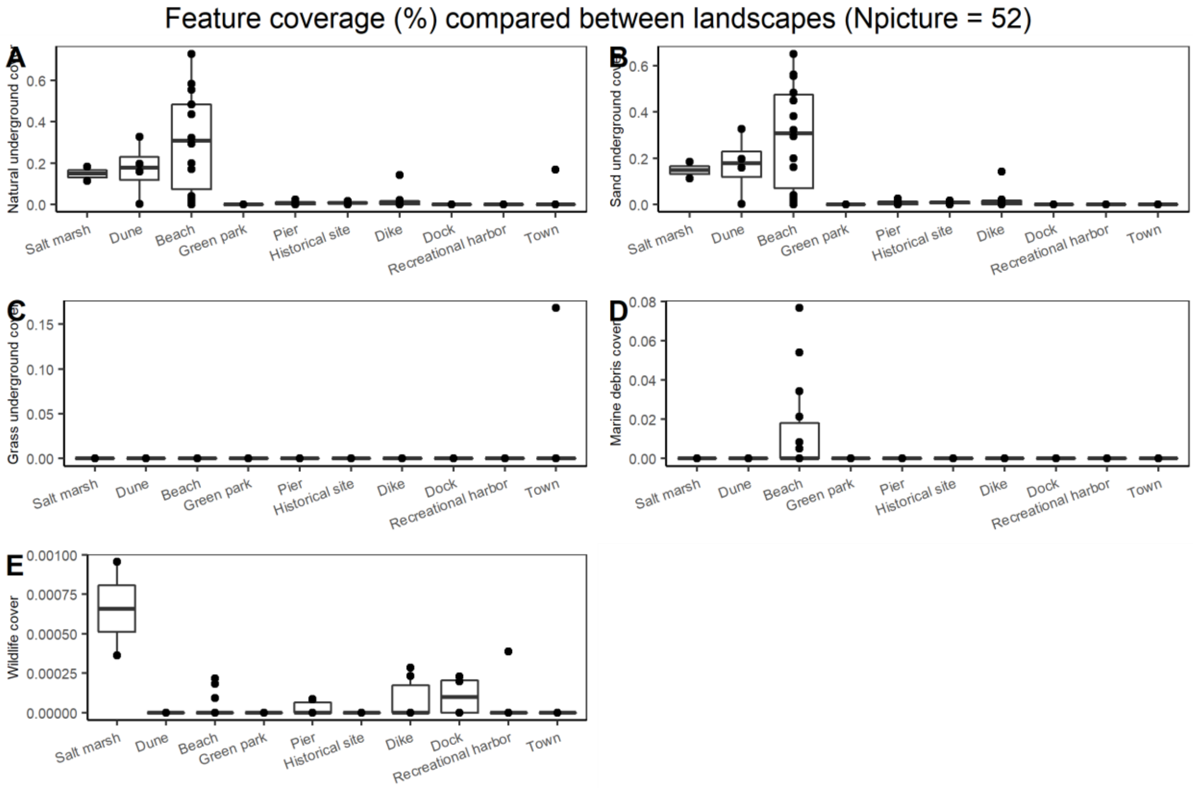

Figure S 9: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

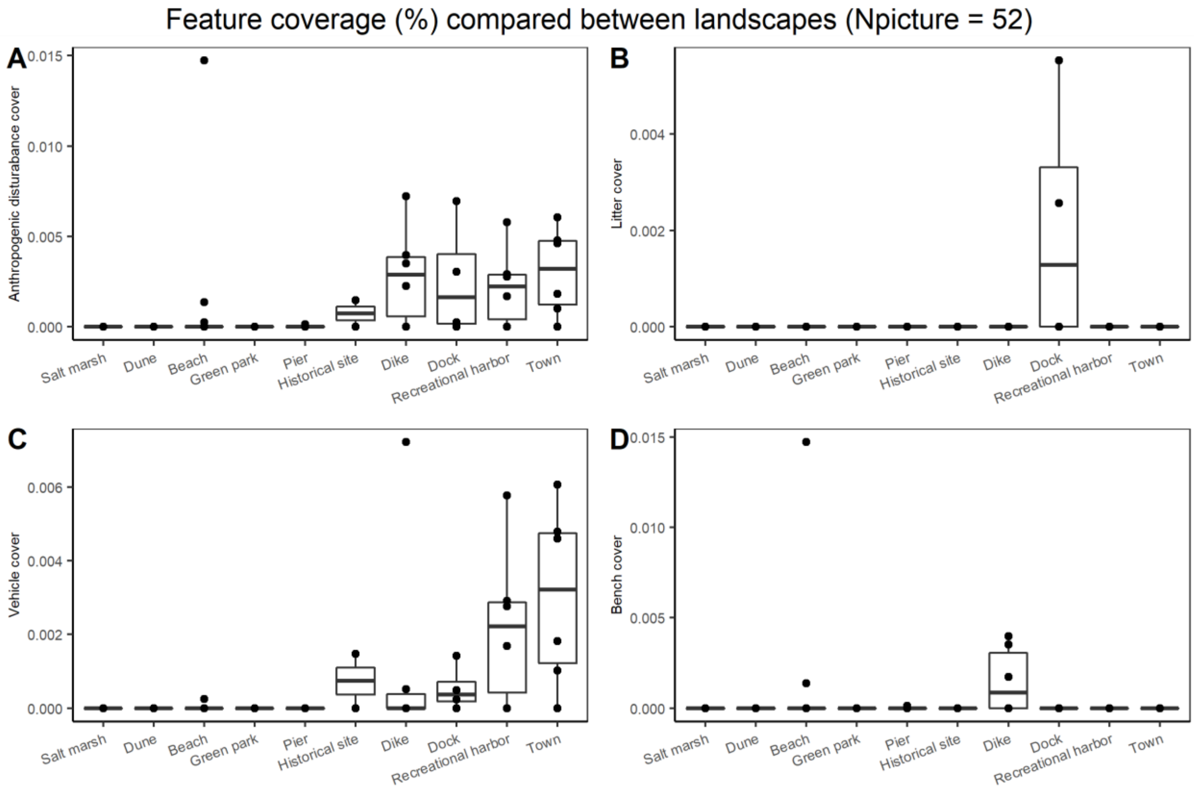

Figure S 10: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

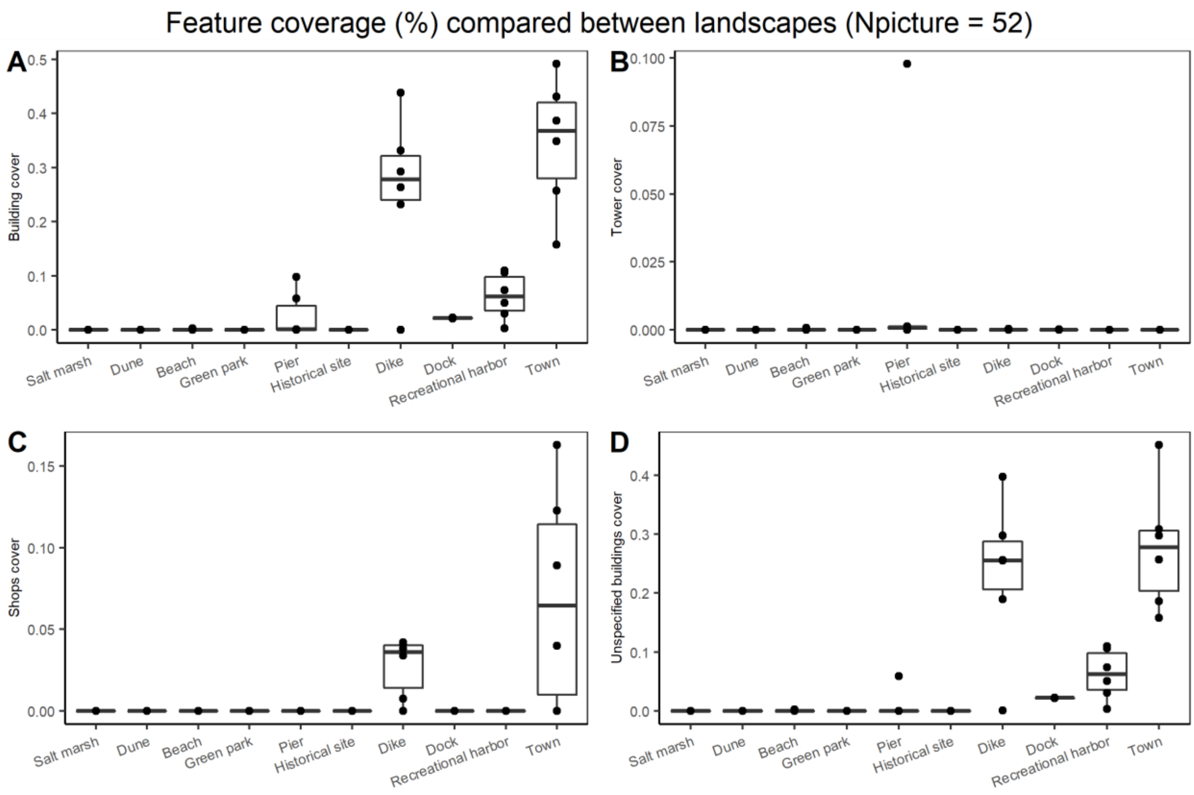

Figure S 11: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

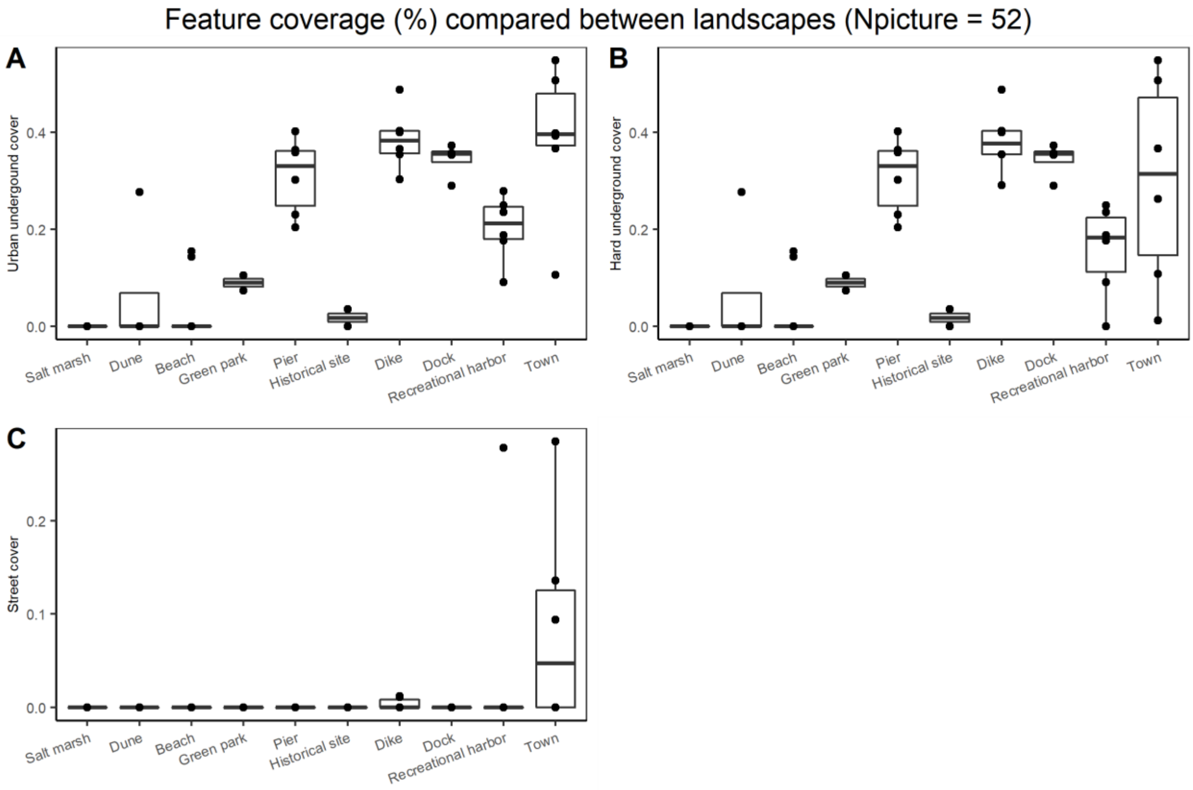

Figure S 12: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

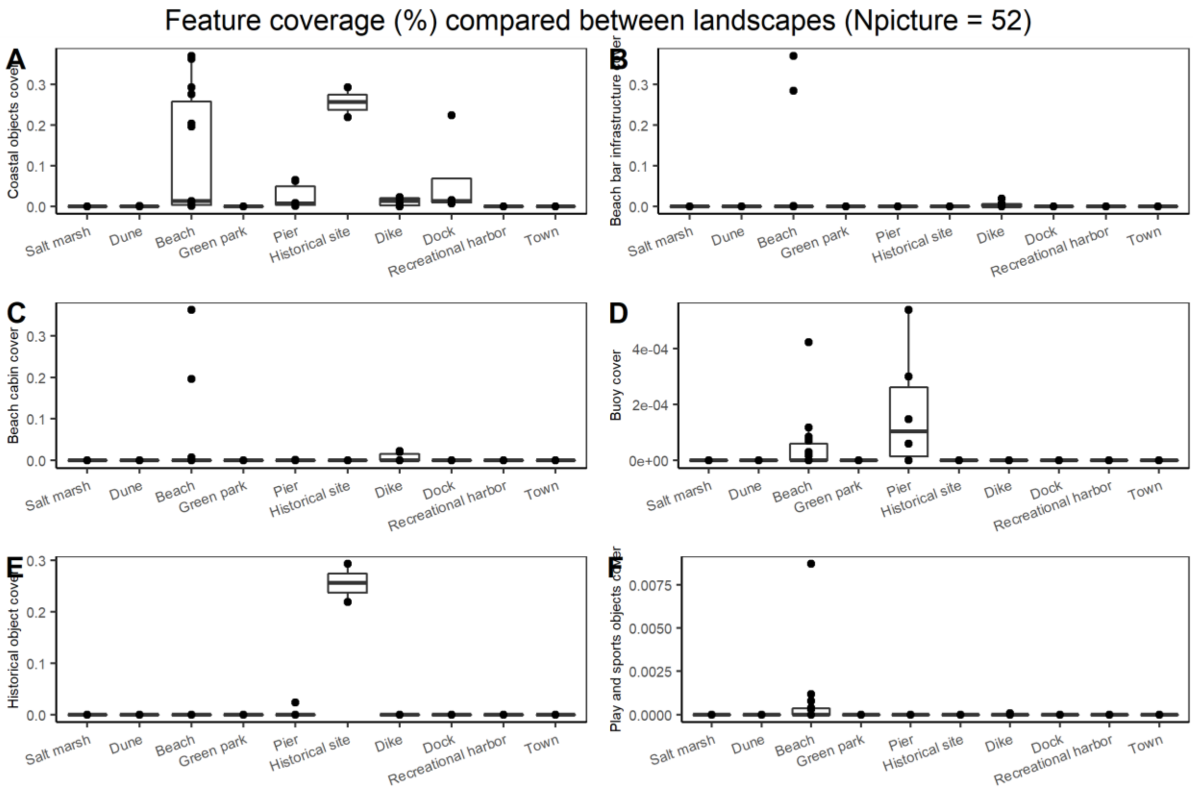

Figure S 13: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

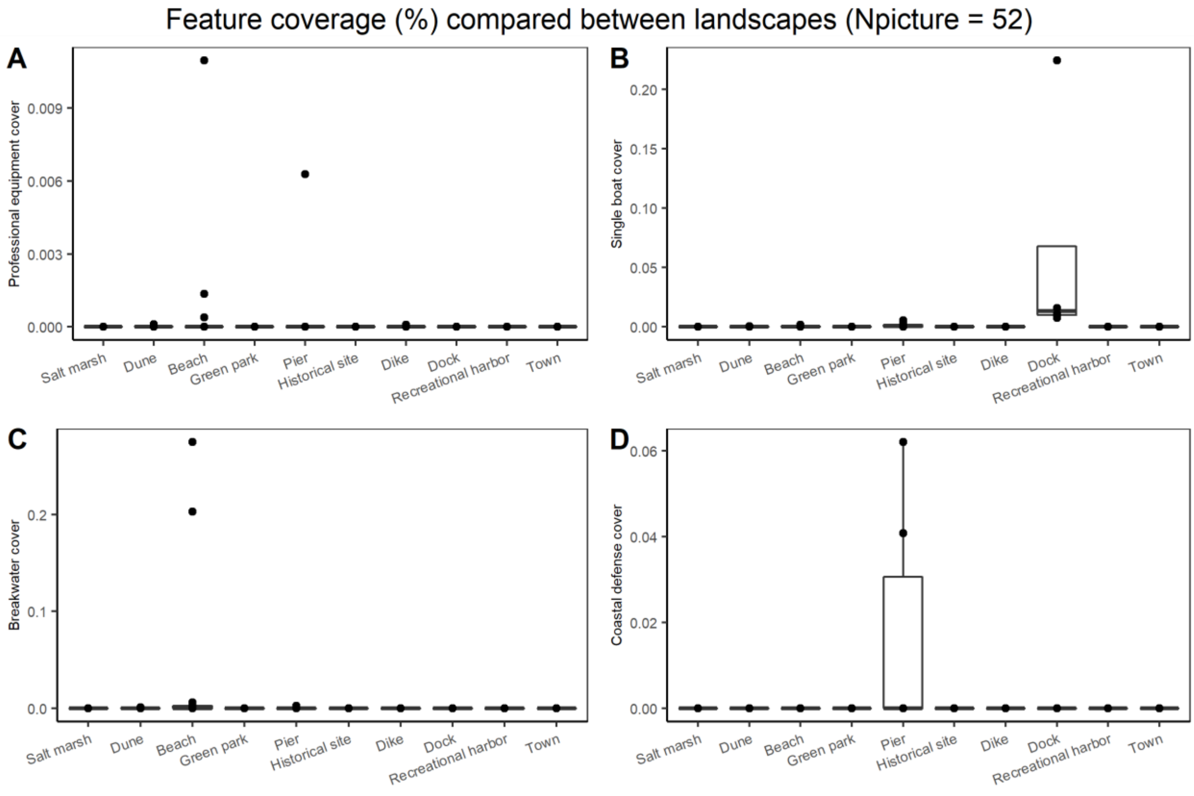

Figure S 14: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

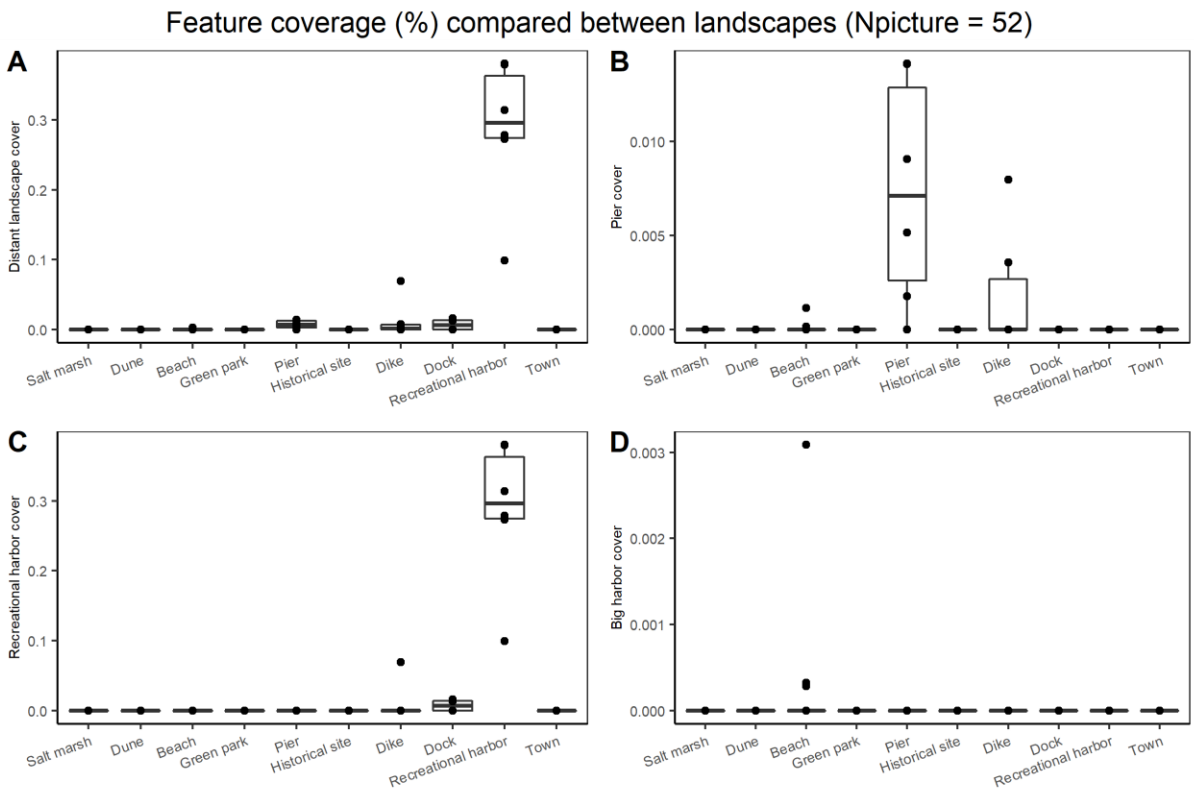

Figure S 15: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

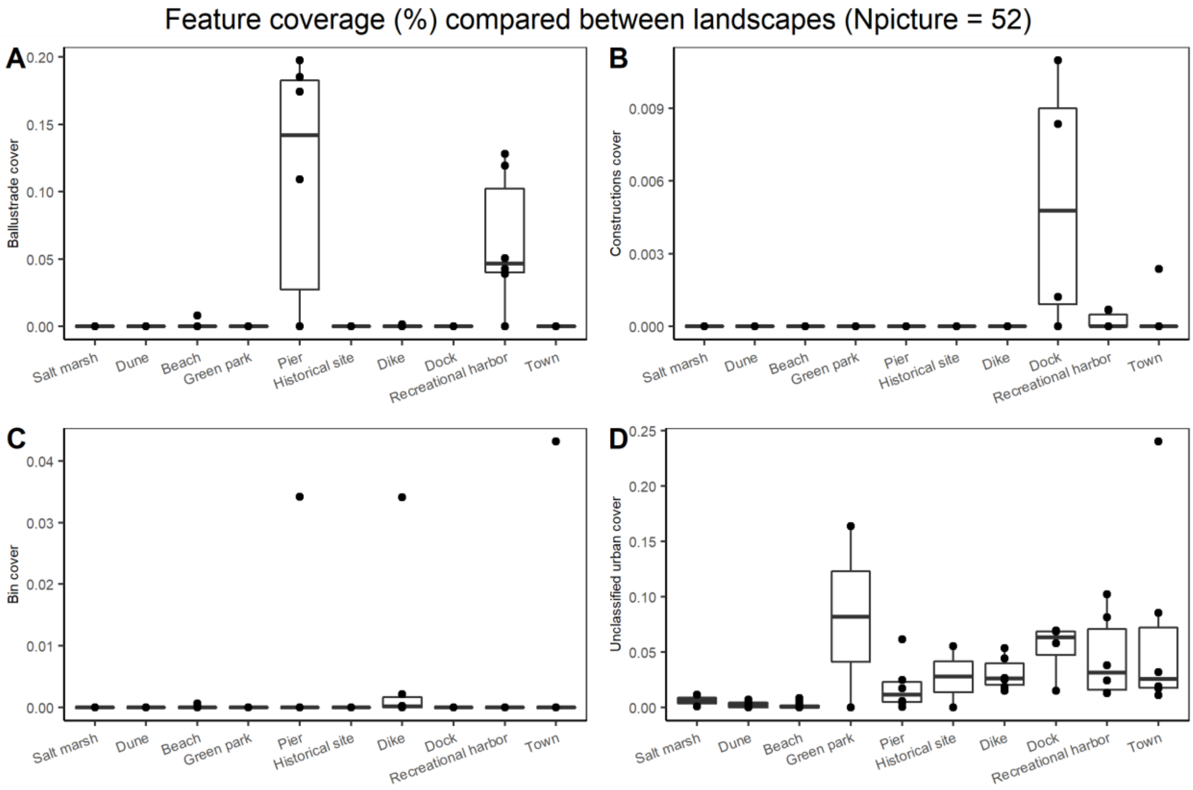

Figure S 16: Some of the picture content of 52 pictures of the diverse landscapes plotted as points and boxplots.

Modelled estimates

Table S 6: Model estimates and model fit parameters of separate linear models (ANOVA) that explained differences in picture content between landscapes.

	Model estimates					Model fit parameters			
Component	**B**	**SE**	**t-value**	**p-value**	**p-value (BH-adjusted)**	$R^2_{(marginal)}$	$R^2_{(conditional)}$	**AIC**	**BIC**
Natural	0.092	0.092	0.997	0.325	0.956	0.787	0.742	-32.593	-11.130
Vegetation	-0.040	0.040	-1.003	0.321	0.956	0.923	0.906	-118.753	-97.290
Landplant	-0.041	0.025	-1.680	0.100	0.665	0.951	0.940	-169.458	-147.995
Dune vegetation	0.000	0.026	-0.004	0.997	1.000	0.913	0.894	-162.750	-141.287
Salt marsh vegetation	0.000	0.006	0.000	1.000	1.000	0.978	0.973	-312.180	-290.717
Flower box	0.001	0.000	3.487	0.001	0.061	0.401	0.273	-609.441	-587.977
Water	0.007	0.059	0.111	0.912	1.000	0.260	0.102	-79.202	-57.738
Brackish water	0.000	0.000	0.000	1.000	1.000	0.999	0.999	-686.055	-664.592
Seawater	0.007	0.059	0.111	0.912	1.000	0.270	0.114	-79.203	-57.739
Still water	0.006	0.039	0.160	0.873	1.000	0.396	0.267	-121.860	-100.396
Waves	0.000	0.042	0.006	0.995	1.000	0.109	-0.082	-114.157	-92.693
Seawater on the beach	0.000	0.006	0.000	1.000	1.000	0.233	0.069	-325.203	-303.739
Sky	0.125	0.063	1.980	0.054	0.411	0.569	0.477	-71.730	-50.266
Blue sky	0.014	0.063	0.215	0.831	1.000	0.189	0.015	-71.191	-49.727
Delineated cumulus	0.085	0.056	1.501	0.141	0.746	0.345	0.204	-83.538	-62.074
Non-delineated cumulus	0.010	0.050	0.201	0.842	1.000	0.133	-0.053	-95.912	-74.448
Stratus and cirrus	0.017	0.077	0.218	0.828	1.000	0.138	-0.047	-51.539	-30.075

Natural underground	0.000	0.082	0.005	0.996	1.000	0.510	0.405	-44.331	-22.867
Sand underground	0.028	0.077	0.371	0.712	1.000	0.532	0.432	-51.697	-30.233
Grass underground	-0.028	0.014	-2.049	0.047	0.411	0.150	-0.032	-230.792	-209.328
Marine debris	0.000	0.008	0.000	1.000	1.000	0.213	0.044	-288.933	-267.470
Wildlife	0.000	0.000	1.344	0.186	0.759	0.605	0.520	-788.379	-766.916
Urban	-0.100	0.086	-1.154	0.255	0.844	0.803	0.761	-38.995	-17.531
Building	-0.086	0.040	-2.170	0.036	0.411	0.803	0.760	-120.352	-98.888
Shops	-0.042	0.014	-3.036	0.004	0.109	0.524	0.422	-229.460	-207.996
Unspecified building	-0.044	0.035	-1.250	0.218	0.826	0.784	0.738	-132.918	-111.454
Tower	0.000	0.008	0.007	0.994	1.000	0.159	-0.021	-287.782	-266.318
Anthropogenic disturbance	0.000	0.002	-0.141	0.889	1.000	0.170	-0.008	-453.953	-432.490
Vehicle	-0.002	0.001	-1.999	0.052	0.411	0.385	0.253	-515.996	-494.532
Litter	0.000	0.000	0.000	1.000	1.000	0.422	0.298	-596.683	-575.219
Bench	0.002	0.001	1.171	0.248	0.844	0.085	-0.111	-474.542	-453.079
Coastal object	0.012	0.052	0.227	0.822	1.000	0.402	0.273	-92.656	-71.192
Beach bar infrastructure	0.005	0.039	0.117	0.907	1.000	0.104	-0.087	-123.062	-101.598
Beach cabin	0.007	0.034	0.208	0.836	1.000	0.098	-0.095	-135.407	-113.943
Buoy	0.000	0.000	0.000	1.000	1.000	0.292	0.140	-803.450	-781.986
Historical object	0.000	0.005	0.000	1.000	1.000	0.975	0.970	-334.618	-313.155
Play and sports objects	0.000	0.001	0.017	0.987	1.000	0.088	-0.107	-534.384	-512.921
Single boat	0.000	0.016	0.002	0.999	1.000	0.310	0.162	-211.732	-190.269
Breakwater	0.000	0.028	0.000	1.000	1.000	0.110	-0.081	-155.698	-134.234
Coastal defense	0.000	0.005	0.000	1.000	1.000	0.294	0.142	-326.257	-304.793

Professional equipment	0.000	0.001	0.015	0.988	1.000	0.071	-0.128	-496.107	-474.643
Urban underground	-0.001	0.048	-0.015	0.988	1.000	0.810	0.770	-99.666	-78.202
Street	-0.082	0.032	-2.558	0.014	0.252	0.256	0.096	-142.324	-120.860
Hard underground	0.081	0.058	1.391	0.171	0.757	0.715	0.654	-79.922	-58.458
Distant landscape	0.013	0.021	0.629	0.533	1.000	0.881	0.856	-184.214	-162.750
Pier	0.002	0.001	1.394	0.171	0.757	0.544	0.446	-469.210	-447.746
Recreational harbor	0.012	0.021	0.539	0.593	1.000	0.882	0.857	-184.198	-162.734
Big harbor	0.000	0.000	0.000	1.000	1.000	0.075	-0.123	-641.520	-620.057
Bin	-0.001	0.005	-0.213	0.833	1.000	0.120	-0.069	-330.233	-308.770
Balustrade	0.000	0.021	0.012	0.991	1.000	0.585	0.497	-187.469	-166.005
Constructions	0.000	0.001	-0.464	0.645	1.000	0.510	0.405	-519.449	-497.985
Unclassified urban	-0.037	0.023	-1.597	0.118	0.693	0.330	0.187	-176.075	-154.611
People	0.008	0.010	0.840	0.406	1.000	0.193	0.021	-266.298	-244.835

2.1.4. Data-exploration of PRS

Although that the PRS is not normally distributed, considering the large sample size, the PRS seems normal enough for linear model analyses.

Normality test (Shapiro Wilk): W = 0.9886, p-value < 2.2e-16

Histogram

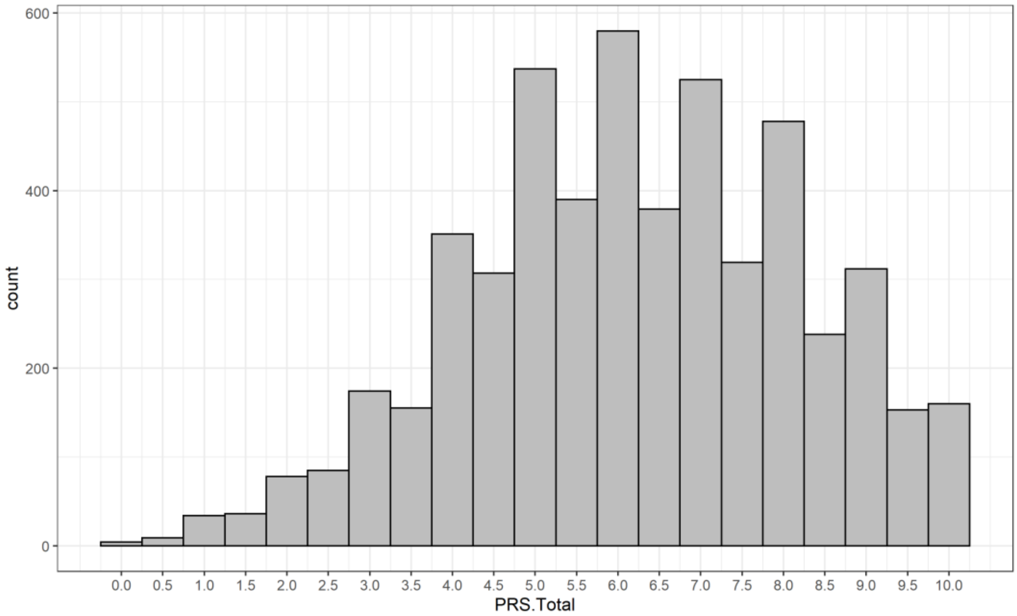

Figure S 17: Histogram of PRS from all participants on all pictures.

QQ-plot

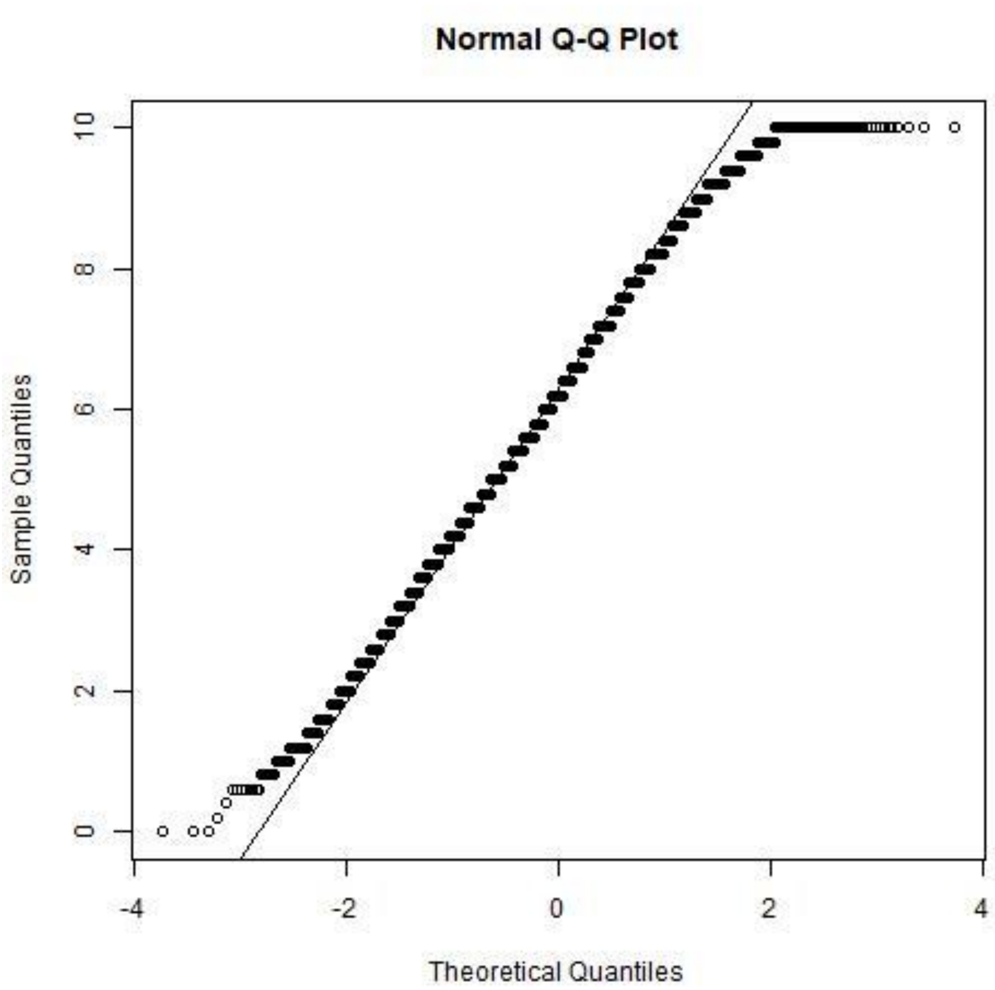

Figure S 18: QQ-plot of PRS scores from all participants on all pictures.

Cronbach-alpha calculation of all multi-item questionnaires assessed either as outcome or covariate.

Table S 7: Cronbach-alpha calculation of the adapted Perceived Restorativeness Scale used in the study.

Questionnaire	Item	Raw alpha	Standardized Alpha	Raw alpha if item is dropped	Standardized alpha if item is dropped
Adapted Perceived Restorativeness Scale	Restoration	0.90	0.90	0.85	0.85
	Fascination			0.87	0.88
	Being away			0.87	0.87
	Coherence			0.92	0.92
	Compatibility			0.86	0.87

2.2. Results

2.2.1. Inter-environment variation in PRS: ten coastal environments compared

Model without covariates

Model formulation

Data
$N_{participants}$: 102
$N_{pictures}$: 52
$N_{modelled}$: 102 * 52 = 5304 records

Linear mixed effects model
Random effects: ID, Picture
Fixed effects: Ten coastal environments inclusive five beach environments: beaches (open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar), piers, dunes, salt marshes, green parks, dikes, towns, recreational harbors, docks, and historical sites.
Covariates: /

Model assumptions

Does the model meet the assumption of independency and normality of residuals?

Independency
Random effects variances show that the residual variance is larger than the variance of ID and Picture. Thus, there is no dependency of samples within ID or Picture, and this assumption is met.

Table S 8: Random effects' variance structure of the model.

Random effects	Variance
ID	0.974
Picture	0.345
Residual	1.637

Normality of residuals
Distribution of residuals is satisfactory, despite inconsistencies at high PRS values.

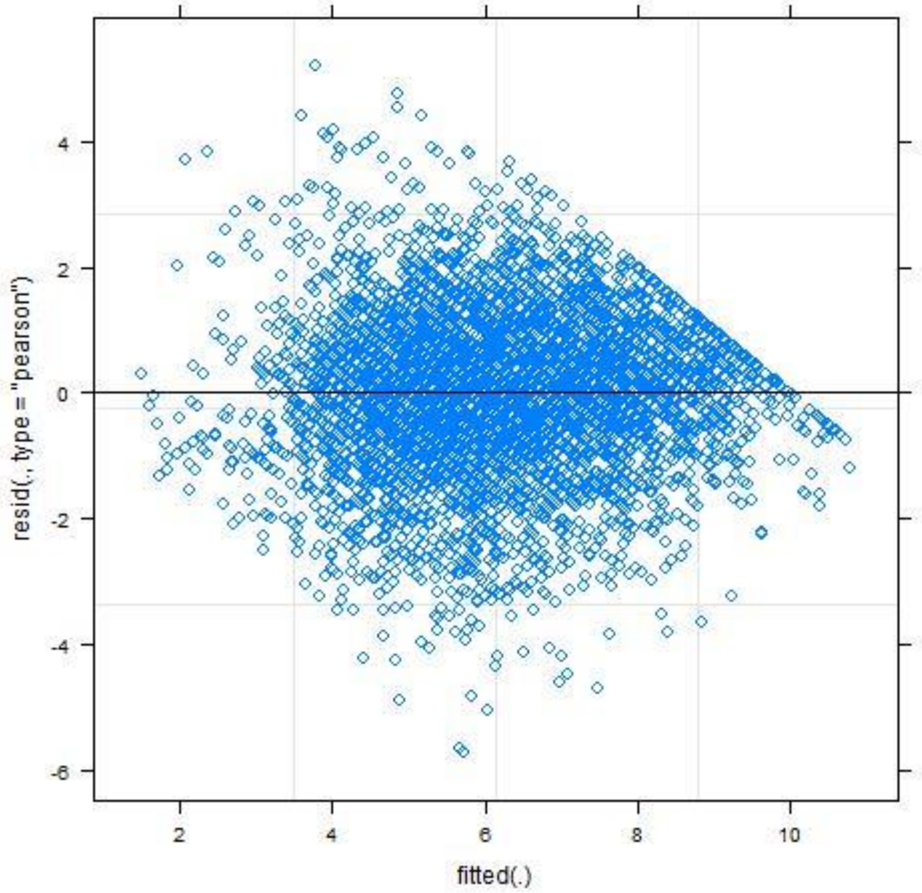

Figure S 19: Residuals (y) over fitted (x) values of the model.

Model interpretation

Results of the ANOVA.

Table S 9: Results of the ANOVA.

	Summed squares	**Mean squares**	**df**	**F-value**	**p-value**
Ten coastal environments inclusive five beach environments	265.177	29.464	9	17.997	<0.001

Estimated marginal means

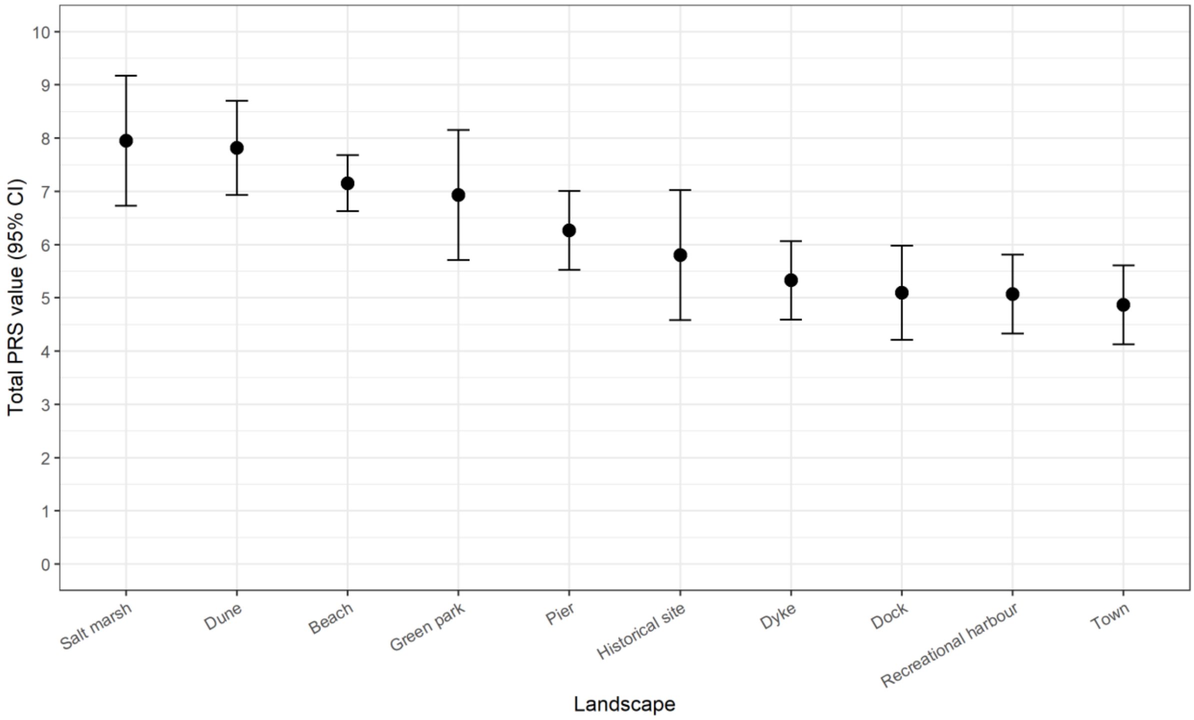

Figure S 20: Estimated marginal means of PRS per landscape based on the model.

Table S 10: Pairwise differences between the estimated marginal means.

Pairwise difference	Estimate	SE	z-ratio	p-value
Salt marsh - Dune	0.132	0.520	0.253	1.000
Salt marsh - Beach	0.797	0.454	1.754	0.764
Salt marsh - Green park	1.018	0.601	1.694	0.799
Salt marsh - Pier	1.686	0.491	3.436	0.021
Salt marsh - Historical site	2.150	0.601	3.578	0.013
Salt marsh - Dike	2.621	0.491	5.343	<0.001
Salt marsh - Dock	2.853	0.520	5.484	<0.001
Salt marsh - Recreational harbor	2.879	0.491	5.869	<0.001
Salt marsh - Town	3.083	0.491	6.284	<0.001
Dune - Beach	0.665	0.341	1.952	0.633
Dune - Green park	0.886	0.520	1.702	0.795
Dune - Pier	1.554	0.388	4.006	0.002
Dune - Historical site	2.018	0.520	3.878	0.004
Dune - Dike	2.489	0.388	6.418	<0.001
Dune - Dock	2.722	0.425	6.406	<0.001
Dune - Recreational harbor	2.748	0.388	7.084	<0.001
Dune - Town	2.951	0.388	7.609	<0.001

Beach - Green park	0.221	0.454	0.486	1.000
Beach - Pier	0.889	0.293	3.032	0.074
Beach - Historical site	1.353	0.454	2.979	0.085
Beach - Dike	1.824	0.293	6.223	<0.001
Beach - Dock	2.057	0.341	6.037	<0.001
Beach - Recreational harbor	2.083	0.293	7.103	<0.001
Beach - Town	2.286	0.293	7.798	<0.001
Green park - Pier	0.668	0.491	1.362	0.939
Green park - Historical site	1.132	0.601	1.885	0.680
Green park - Dike	1.604	0.491	3.269	0.036
Green park - Dock	1.836	0.520	3.528	0.015
Green park - Recreational harbor	1.862	0.491	3.795	0.006
Green park - Town	2.065	0.491	4.210	0.001
Pier - Historical site	0.464	0.491	0.947	0.995
Pier - Dike	0.936	0.347	2.697	0.175
Pier - Dock	1.168	0.388	3.011	0.078
Pier - Recreational harbor	1.194	0.347	3.441	0.021
Pier - Town	1.397	0.347	4.028	0.002
Historical site - Dike	0.471	0.491	0.961	0.994
Historical site - Dock	0.703	0.520	1.352	0.941
Historical site - Recreational harbor	0.729	0.491	1.487	0.898
Historical site - Town	0.933	0.491	1.902	0.668
Dike - Dock	0.232	0.388	0.599	1.000
Dike - Recreational harbor	0.258	0.347	0.744	0.999
Dike - Town	0.462	0.347	1.331	0.947
Dock - Recreational harbor	0.026	0.388	0.067	1.000
Dock - Town	0.230	0.388	0.592	1.000
Recreational harbor - Town	0.204	0.347	0.587	1.000

Model with covariates

Model selection

Results of the forward AIC selection.

Table S 11: Results of the forward AIC section.

Variable added to the model	Order	AIC	MarginalR2	ConditionalR2	BIC
Ten coastal environments inclusive five beach environments	Fixed	18200.950	0.276	0.599	18286.441
Near-home air quality	1	18195.817	0.302	0.600	18287.884
Stress in the past month	2	18194.749	0.311	0.600	18293.393
Smoking status	3	18192.642	0.319	0.601	18297.861
Associating the Belgian coast with obligations	4	18190.011	0.328	0.602	18301.807
Gender	5	18189.597	0.334	0.602	18307.969

Model formulation

Data

$N_{participants}$: 102

$N_{pictures}$: 52

$N_{modelled}$: 102 * 52 = 5304 records

Linear mixed effects model

Random effects: ID, Picture

Fixed effects: Ten coastal environments inclusive five beach environments: beaches (open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar), piers, dunes, salt marshes, green parks, dikes, towns, recreational harbors, docks, and historical sites.

Covariates: Near-home air quality + Stress in the past month + Smoking status + Associating the Belgian coast with obligations + Gender

Model assumptions

Does the model meet the assumption of independency and normality of residuals?

Independency

Random effects variances show that the residual variance is larger than the variance of ID and Picture. Thus, there is no dependency of samples within ID or Picture, and this assumption is met.

Table S 12: Random effects' variance structure of the model.

Random effect	Variance
ID	0.760
Picture	0.345
Residual	1.637

Normality of residuals
Distribution of residuals is satisfactory, despite inconsistencies at high PRS values.

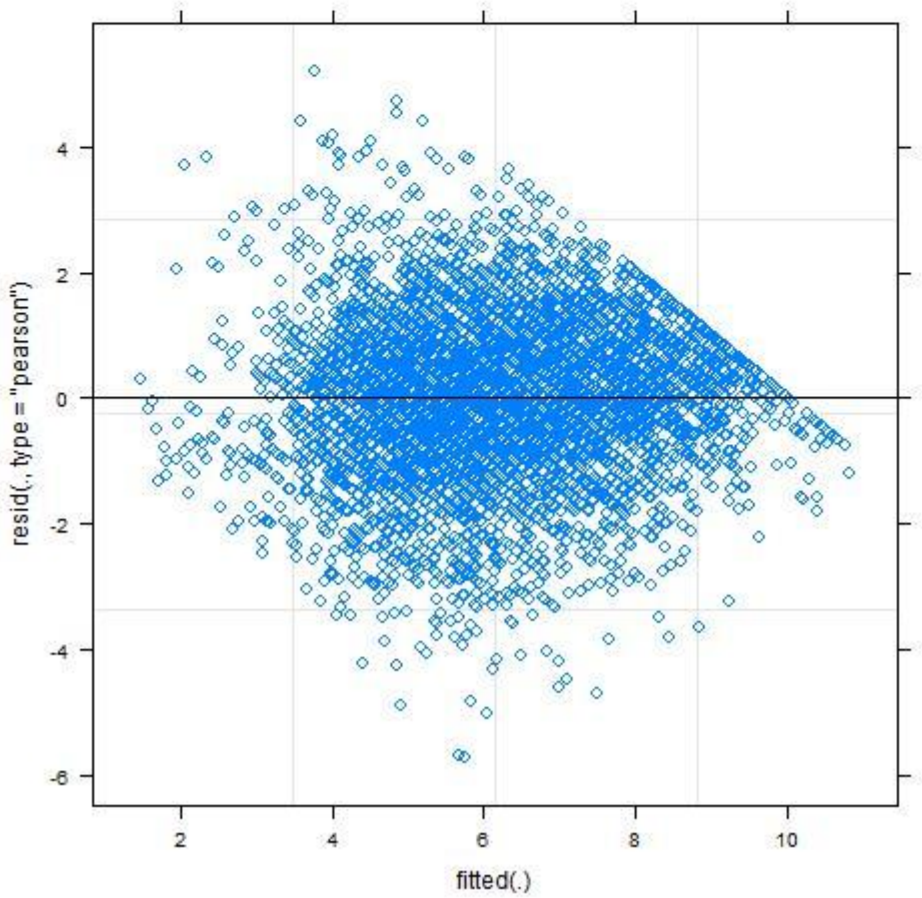

Figure S 21: Residuals (y) over fitted (x) values of the model.

Model interpretation

Results of the ANOVA.

Table S 13: Results of the ANOVA.

	Summed squares	**Mean squares**	**df**	**F-value**	**p-value**
Ten coastal environments inclusive five beach environments	265.216	29.468	9	18.000	<0.001
Near-home air quality	25.852	25.852	1	15.791	<0.001
Stress in the past month	15.055	15.055	1	9.196	0.003
Smoking status	9.092	9.092	1	5.554	0.020
Associating the Belgian coast with obligations	8.351	8.351	1	5.101	0.026
Gender	5.660	5.660	1	3.457	0.066

Estimated marginal means

Table S 14: Estimated marginal means.

Landscape	Estimated marginal mean	SE	Lower CI	Upper CI
Salt marsh	8.543	0.500	7.144	9.942
Dune	8.411	0.399	7.293	9.529
Beach	7.746	0.308	6.883	8.609
Green park	7.525	0.500	6.126	8.925
Pier	6.857	0.360	5.850	7.865
Historical site	6.393	0.500	4.994	7.792
Dike	5.922	0.360	4.915	6.929
Dock	5.690	0.399	4.572	6.808
Recreational harbor	5.664	0.360	4.657	6.671
Town	5.460	0.360	4.453	6.467

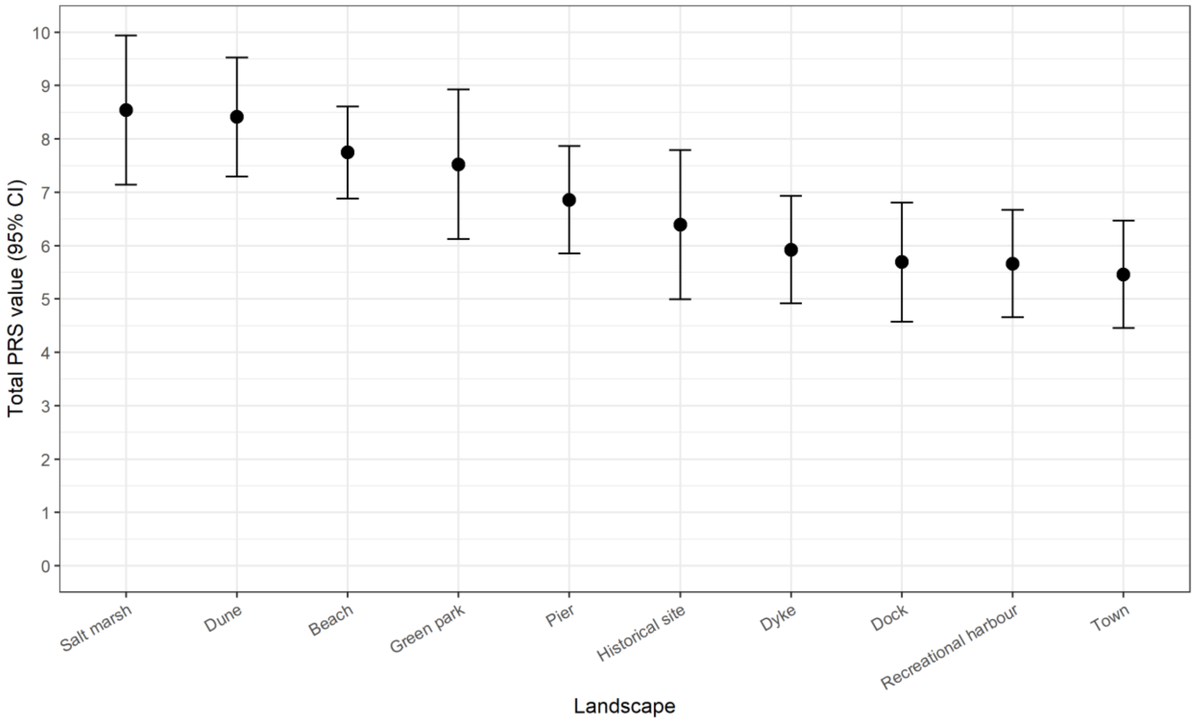

Figure S 22: Estimated marginal means of the ratings for the Perceived Restorativeness Scale (PRS) per a priori defined landscape, based on the model reported for Aim 1.

Estimated pairwise differences between landscapes

Table S 15: Pairwise differences between the estimated marginal means.

Landscape	Estimated marginal mean	SE	Lower CI	Upper CI	Pairwise difference	Estimate	SE	p-value
Salt marsh	8.54	0.50	7.14	9.94	Salt marsh - Dune	0.13	0.52	1.00
					Salt marsh - Beach	0.80	0.45	0.76
					Salt marsh - Green park	1.02	0.60	0.80
					Salt marsh - Pier	1.69	0.49	0.02
					Salt marsh - Historical site	2.15	0.60	0.01
					Salt marsh - Dike	2.62	0.49	<0.01
					Salt marsh - Dock	2.85	0.52	<0.01
					Salt marsh - Recreational harbor	2.88	0.49	<0.01
					Salt marsh - Town	3.08	0.49	<0.01
Dune	8.41	0.40	7.29	9.53	Dune - Beach	0.66	0.34	0.63
					Dune - Green park	0.89	0.52	0.79
					Dune - Pier	1.55	0.39	0.00
					Dune - Historical site	2.02	0.52	0.00
					Dune - Dike	2.49	0.39	<0.01
					Dune - Dock	2.72	0.42	<0.01
					Dune - Recreational harbor	2.75	0.39	<0.01
					Dune - Town	2.95	0.39	<0.01
Beach	7.75	0.31	6.88	8.61	Beach - Green park	0.22	0.45	1.00

					Beach - Pier	0.89	0.29	0.07
					Beach - Historical site	1.35	0.45	0.09
					Beach - Dike	1.82	0.29	<0.01
					Beach - Dock	2.06	0.34	<0.01
					Beach - Recreational harbor	2.08	0.29	<0.01
					Beach - Town	2.29	0.29	<0.01
Green park	7.53	0.50	6.13	8.92	Green park - Pier	0.67	0.49	0.94
					Green park - Historical site	1.13	0.60	0.68
					Green park - Dike	1.60	0.49	0.04
					Green park - Dock	1.84	0.52	0.02
					Green park - Recreational harbor	1.86	0.49	0.01
					Green park - Town	2.07	0.49	<0.01
Pier	6.86	0.36	5.85	7.86	Pier - Historical site	0.46	0.49	0.99
					Pier - Dike	0.94	0.35	0.17
					Pier - Dock	1.17	0.39	0.08
					Pier - Recreational harbor	1.19	0.35	0.02
					Pier - Town	1.40	0.35	<0.01
Historical site	6.39	0.50	4.99	7.79	Historical site - Dike	0.47	0.49	0.99
					Historical site - Dock	0.70	0.52	0.94
					Historical site - Recreational harbor	0.73	0.49	0.90
					Historical site - Town	0.93	0.49	0.67
Dike	5.92	0.36	4.91	6.93	Dike - Dock	0.23	0.39	1.00
					Dike - Recreational harbor	0.26	0.35	1.00

					Dike - Town	0.46	0.35	0.95
Dock	5.69	0.40	4.57	6.81	Dock - Recreational harbor	0.03	0.39	1.00
					Dock - Town	0.23	0.39	1.00
Recreational harbor	5.66	0.36	4.66	6.67	Recreational harbor - Town	0.20	0.35	1.00
Town	5.46	0.36	4.45	6.47	/	/	/	/

2.2.2. Intra-environment variation in PRS: five beach environments compared

Model without covariates

Model formulation

Data
$N_{participants}$: 102
$N_{pictures}$: 52
$N_{modelled}$: 102 * 10 = 1020 records

Linear mixed effects model
Random effects: ID, Picture
Fixed effects: Five beach environments: open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar
Covariates: /

Model assumptions

Does the model meet the assumption of independency and normality of residuals?

Independency
Random effects variances show that the residual variance is larger than the variance of ID and Picture. Thus, there is no dependency of samples within ID or Picture, and this assumption is met.

Table S 16: Random effects' variance structure of the model.

Random effects	Variance
ID	1.312
Picture	0.235
Residual	1.383

Normality of residuals
Distribution of residuals is satisfactory, despite inconsistencies at high PRS values.

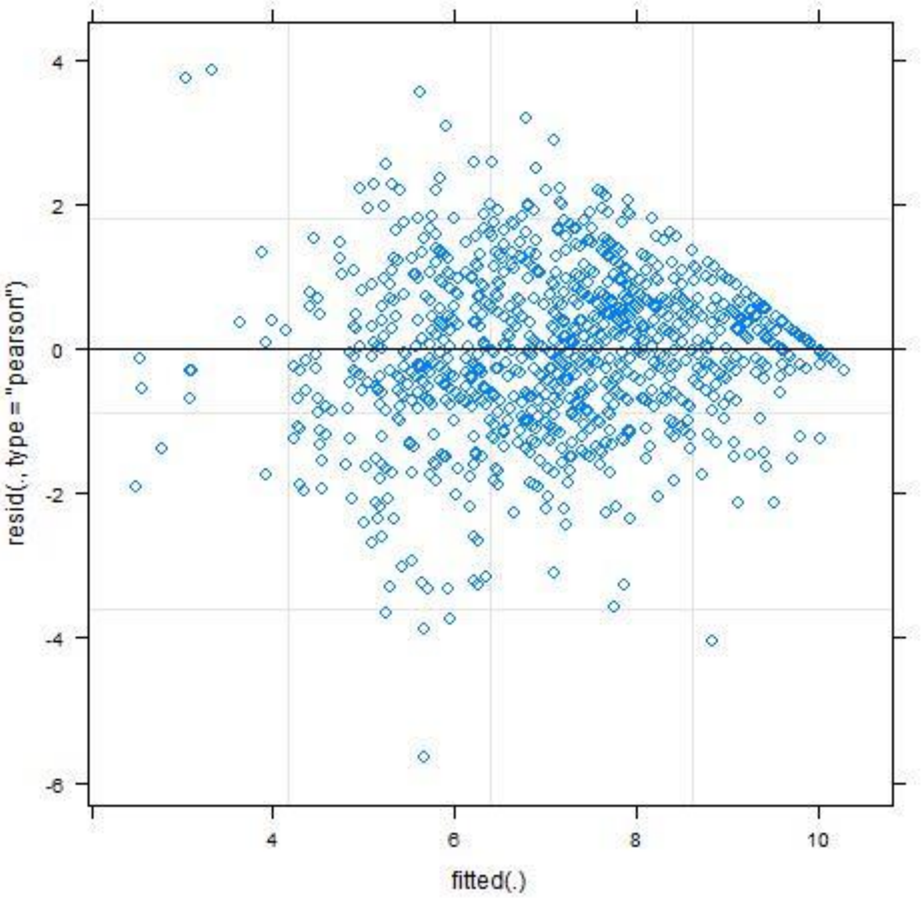

Figure S 23: Residuals (y) over fitted (x) values of the model.

Model interpretation

Results of the ANOVA.

Table S 17: Results of the ANOVA.

	Summed squares	**Mean squares**	**df**	**F-value**	**p-value**
Five beach environments: open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar	40.213	10.053	4	7.270	0.026

Estimated marginal means

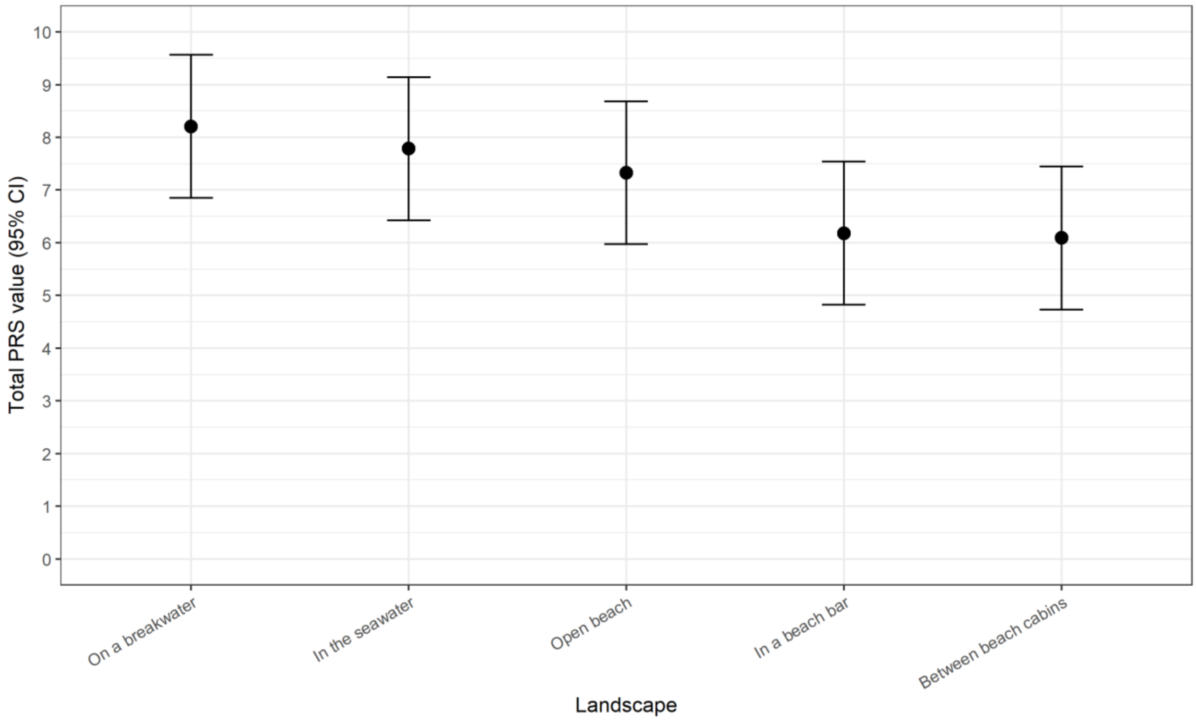

Figure S 24: Estimated marginal means of PRS per landscape based on the model.

Table S 18: Pairwise differences between the estimated marginal means.

Pairwise difference	**Estimate**	**SE**	**z-ratio**	**p-value**
On a breakwater - In the seawater	0.423	0.498	0.848	0.904
On a breakwater - Open beach	0.878	0.498	1.764	0.477
On a breakwater - In a beach bar	2.025	0.498	4.066	0.048
On a breakwater - Between beach cabins	2.117	0.498	4.250	0.040
In the seawater - Open beach	0.456	0.498	0.915	0.880
In the seawater - In a beach bar	1.603	0.498	3.218	0.108
In the seawater - Between beach cabins	1.694	0.498	3.401	0.090
Open beach - In a beach bar	1.147	0.498	2.303	0.279
Open beach - Between beach cabins	1.238	0.498	2.486	0.231
In a beach bar - Between beach cabins	0.091	0.498	0.183	1.000

Model with covariates

Model selection

Results of the forward AIC selection.

Table S 19: Results of the forward AIC section.

Variable added to the model	Order	AIC	MarginalR2	ConditionalR2	BIC
Five beach environments: open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar	Fixed	3503.916	0.198	0.621	3543.336
Gender	1	3500.663	0.219	0.623	3545.011
Coastal relatedness	2	3496.202	0.249	0.624	3545.477
Burnout score	3	3491.466	0.274	0.625	3545.669
Diet	4	3488.680	0.290	0.626	3547.810
Smoking status	5	3487.364	0.299	0.627	3551.422
Near-home access to green spaces	6	3485.087	0.320	0.629	3563.928
Near-home air quality	7	3483.234	0.341	0.630	3567.003

Model formulation

Data

$N_{participants}$: 102

$N_{pictures}$: 10

$N_{modelled}$: 102 * 10 = 1020 records

Linear mixed effects model

Random effects: ID, Picture

Fixed effects: Five beach environments: open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar

Covariates: Gender + Coastal relatedness + Burnout score + Diet + Smoking status + Near-home access to green spaces + Near-home air quality

Model assumptions

Does the model meet the assumption of independency and normality of residuals?

Independency

Random effects variances show that the residual variance is larger than the variance of ID and Picture. Thus, there is no dependency of samples within ID or Picture, and this assumption is met.

Table S 20: Random effects' variance structure of the model.

Random effects	Variance
ID	0.844
Picture	0.235
Residual	1.383

Normality of residuals

Distribution of residuals is satisfactory, despite inconsistencies at high PRS values.

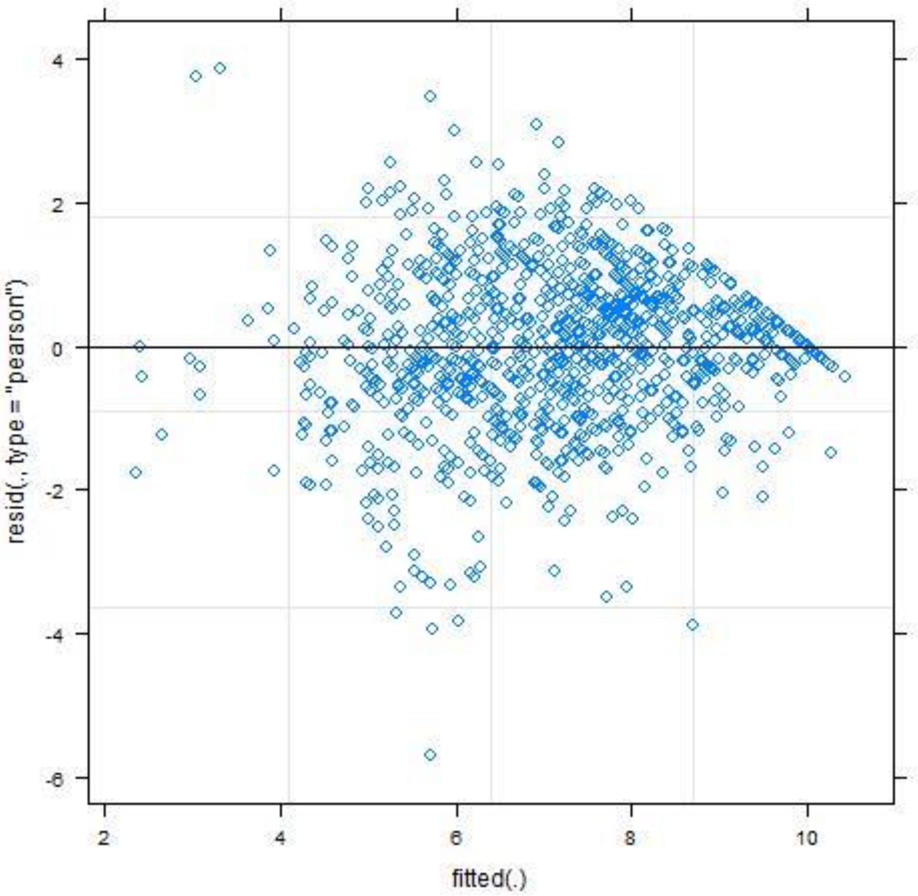

Figure S 25: Residuals (y) over fitted (x) values of the model.

Model interpretation

Results of the ANOVA.

Table S 21: Results of the ANOVA.

	Summed squares	**Mean squares**	**df**	**F-value**	**p-value**
Five beach environments: open beach, in the seawater, on a breakwater, between beach cabins, in a beach bar	40.216	10.054	4	7.271	0.026
Gender	21.397	21.397	1	15.474	<0.001
Coastal relatedness	13.956	13.956	1	10.093	0.002
Burnout score	10.317	10.317	1	7.461	0.008
Diet	9.103	9.103	1	6.583	0.012
Smoking status	10.923	10.923	1	7.899	0.006
Near-home access to green spaces	12.559	4.186	3	3.027	0.033
Near-home air quality	11.172	11.172	1	8.079	0.006

Estimated marginal means

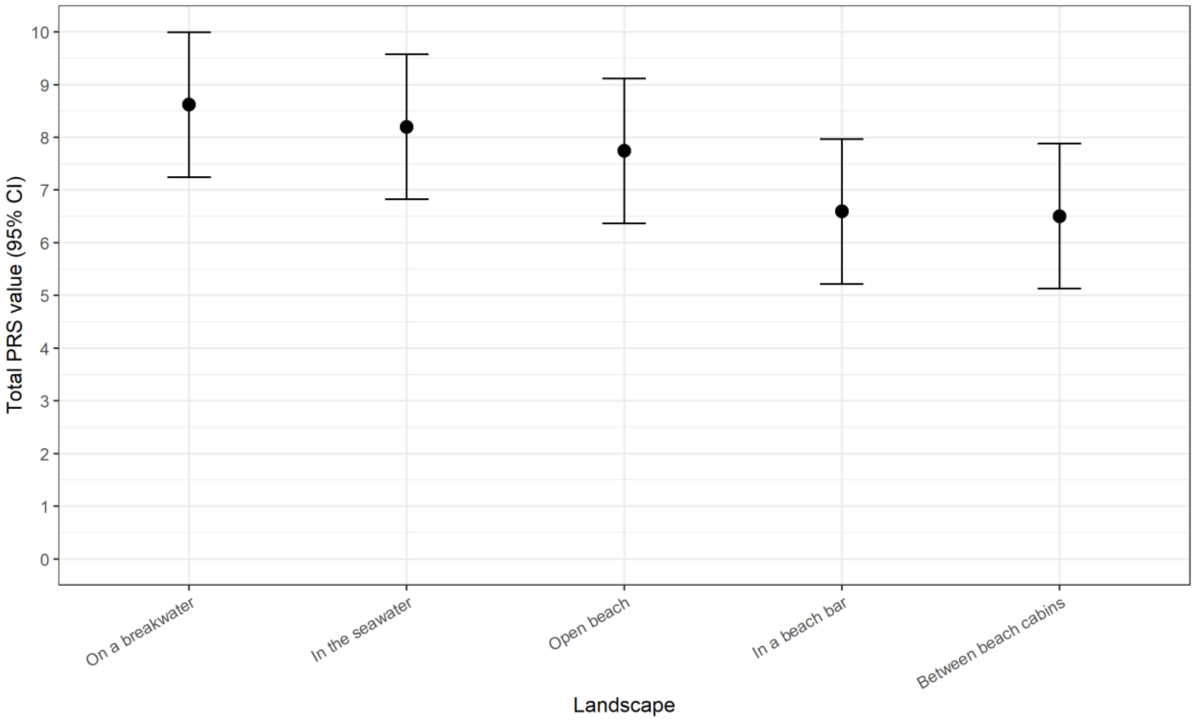

Figure S 26: Estimated marginal means of PRS per landscape based on the model.

Table S 22: Pairwise differences between the estimated marginal means.

Sub-landscape	**Estimated marginal mean**	**SE**	**df**	**Lower CI**	**Upper CI**	**Pairwise difference**	**B**	**SE**	**p-value**
On a breakwater	8.62	0.47	15.24	7.24	9.99	On a breakwater - In the seawater	0.42	0.50	0.904
						On a breakwater - Open beach	0.88	0.50	0.477
						On a breakwater - In a beach bar	2.03	0.50	0.048
						On a breakwater - Between beach cabins	2.12	0.50	0.040
In the seawater	8.20	0.47	15.24	6.82	9.57	In the seawater - Open beach	0.46	0.50	0.880
						In the seawater - In a beach bar	1.60	0.50	0.108
						In the seawater - Between beach cabins	1.69	0.50	0.090
Open beach	7.74	0.47	15.24	6.37	9.12	Open beach - In a beach bar	1.15	0.50	0.279
						Open beach - Between beach cabins	1.24	0.50	0.231
In a beach bar	6.59	0.47	15.24	5.22	7.97	In a beach bar - Between beach cabins	0.09	0.50	1.000
Between beach cabins	6.50	0.47	15.24	5.13	7.88	/	/	/	/

2.2.3. Influence of environmental content

Linear regression graphs

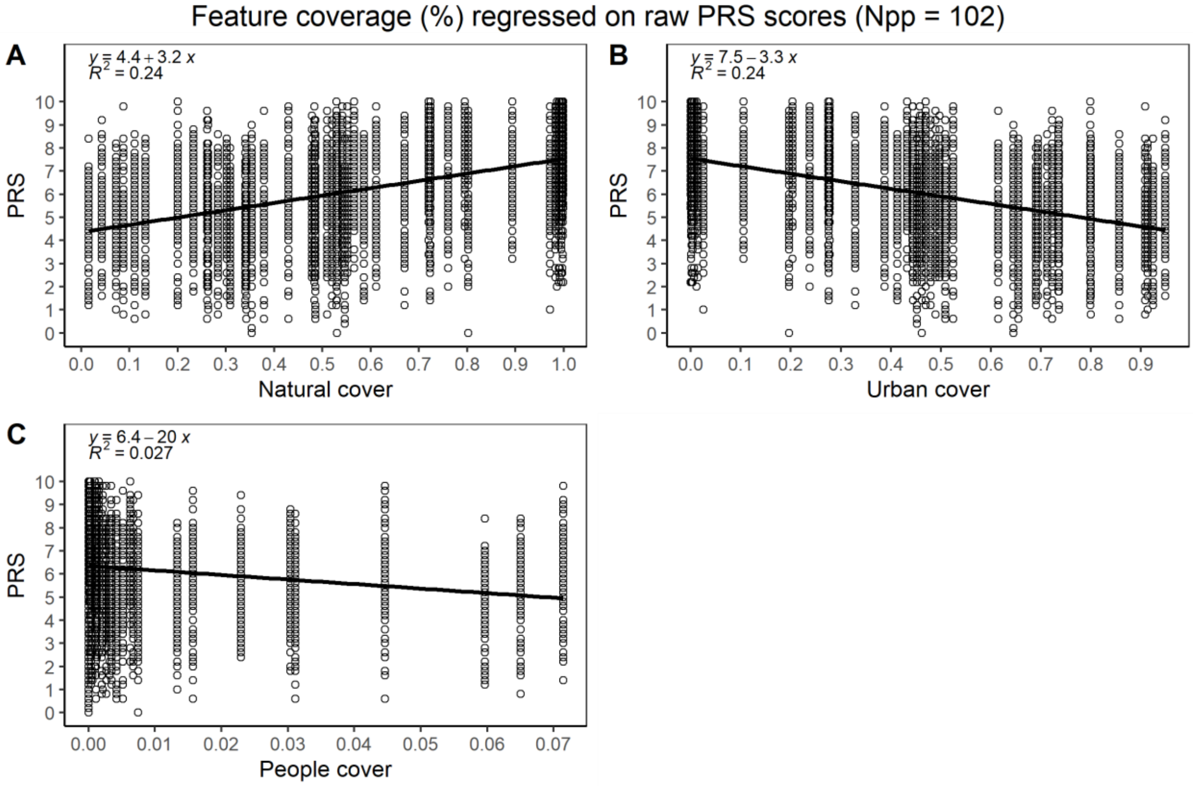

Figure S 27: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

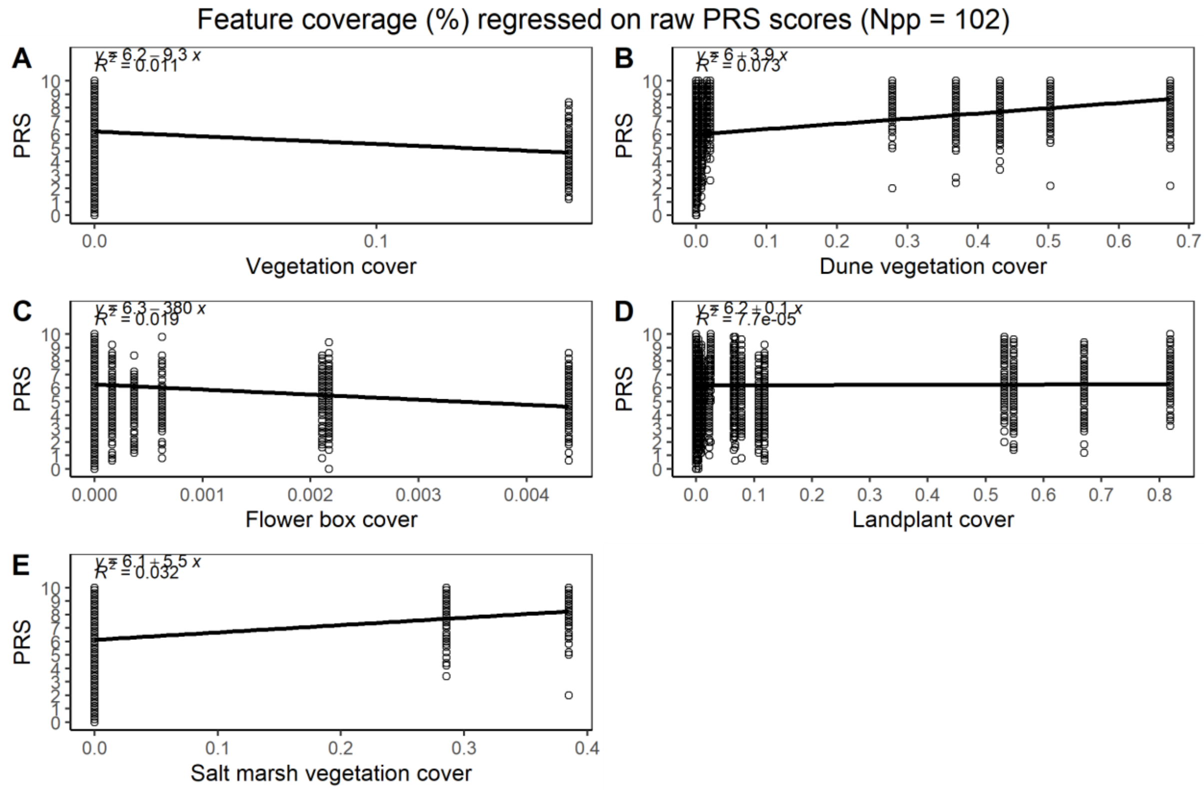

Figure S 28: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

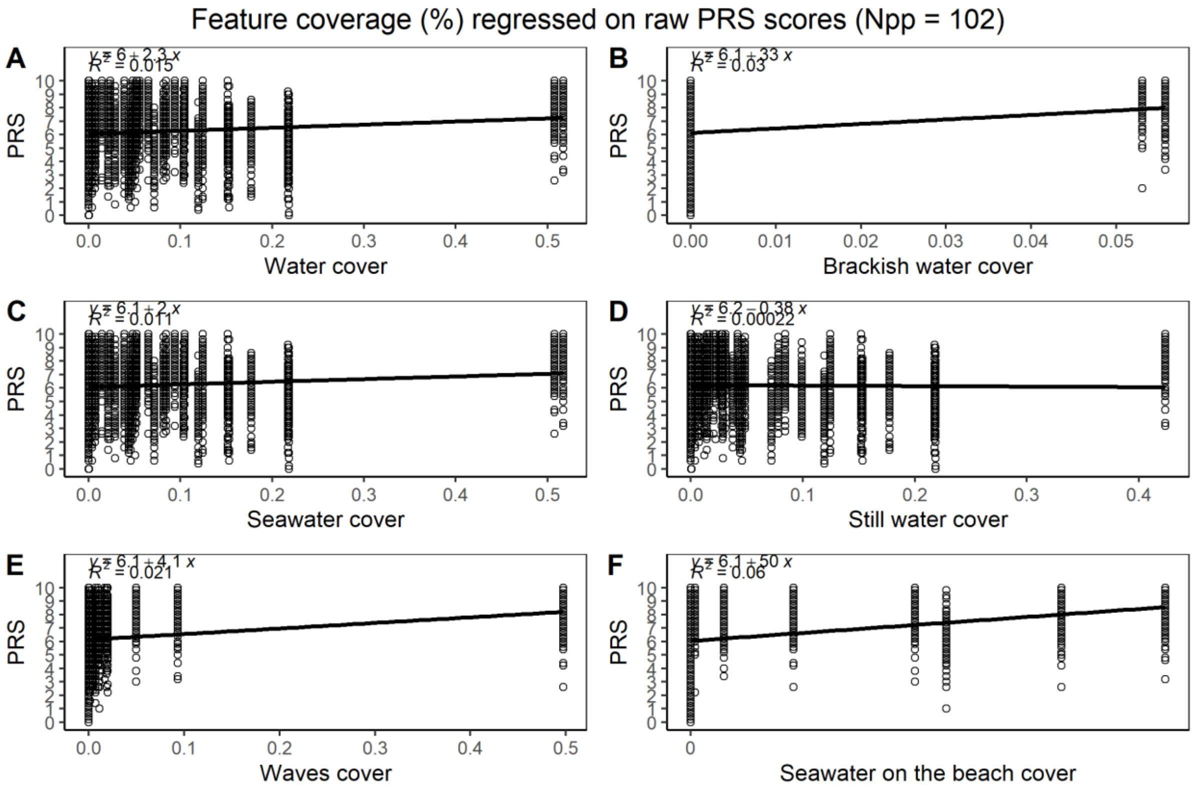

Figure S 29: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

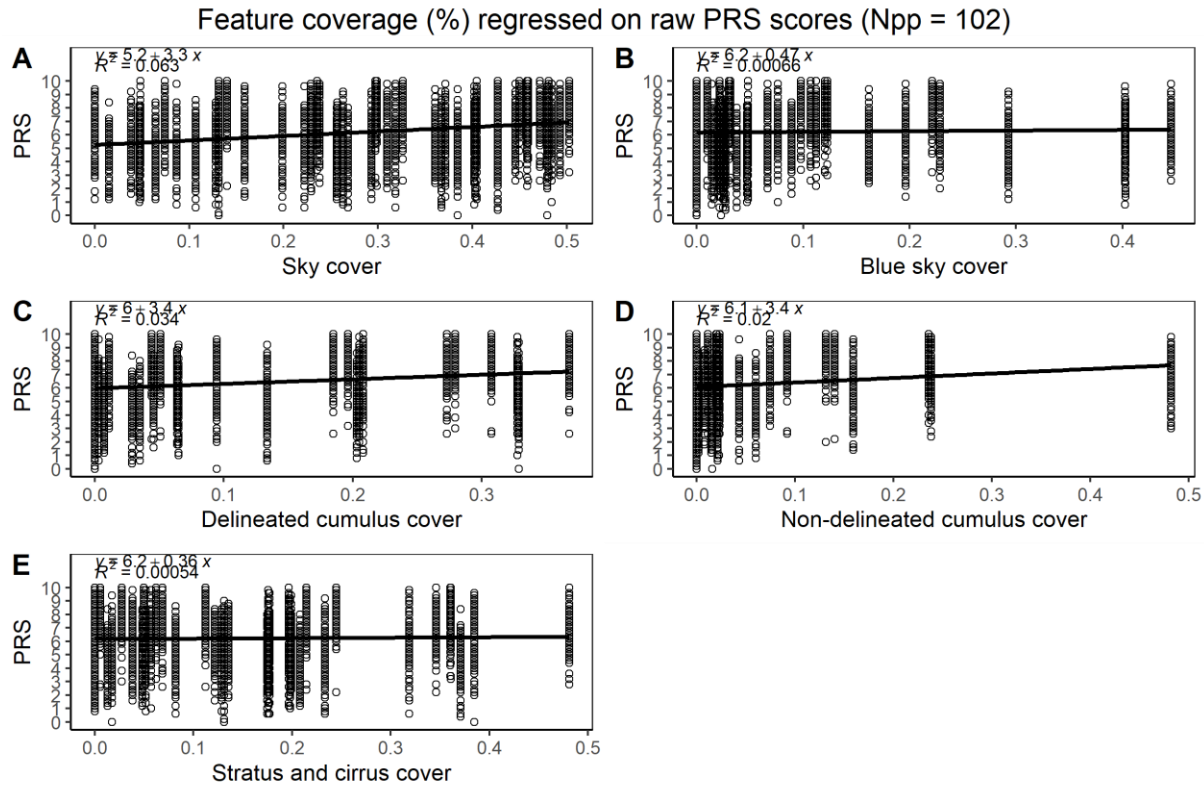

Figure S 30: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

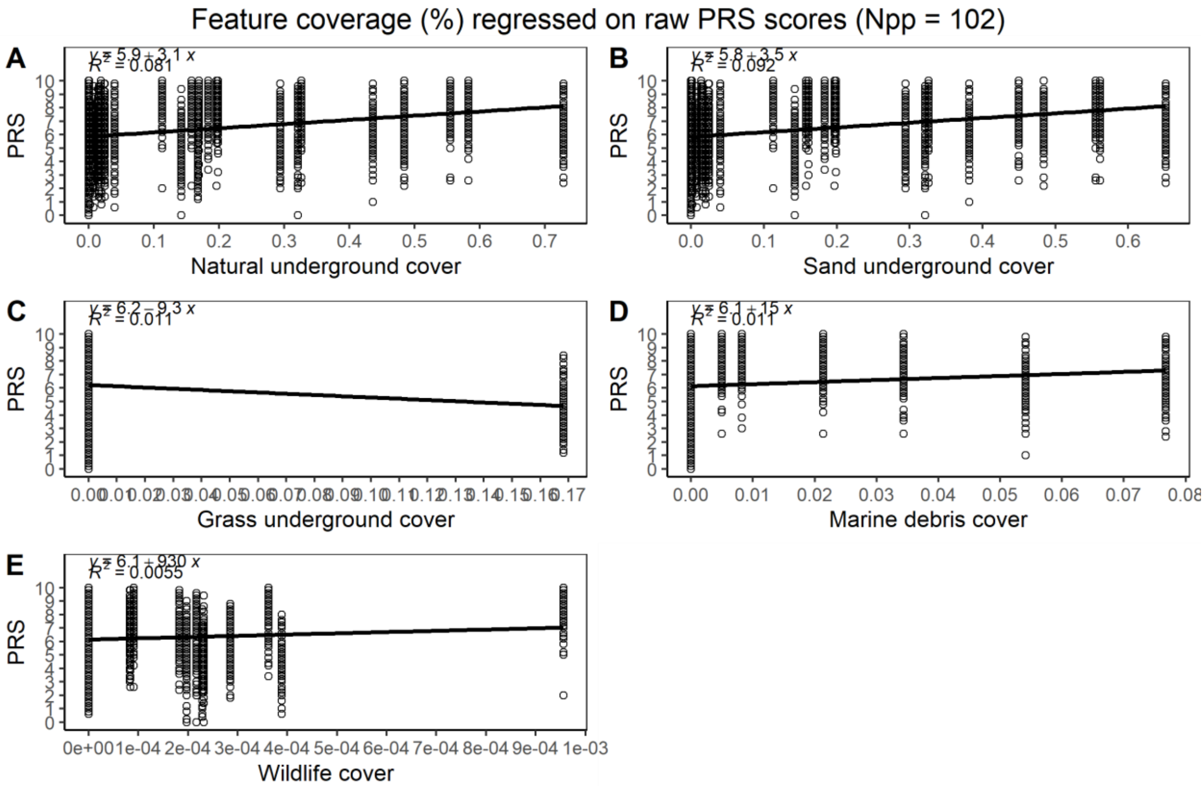

Figure S 31: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

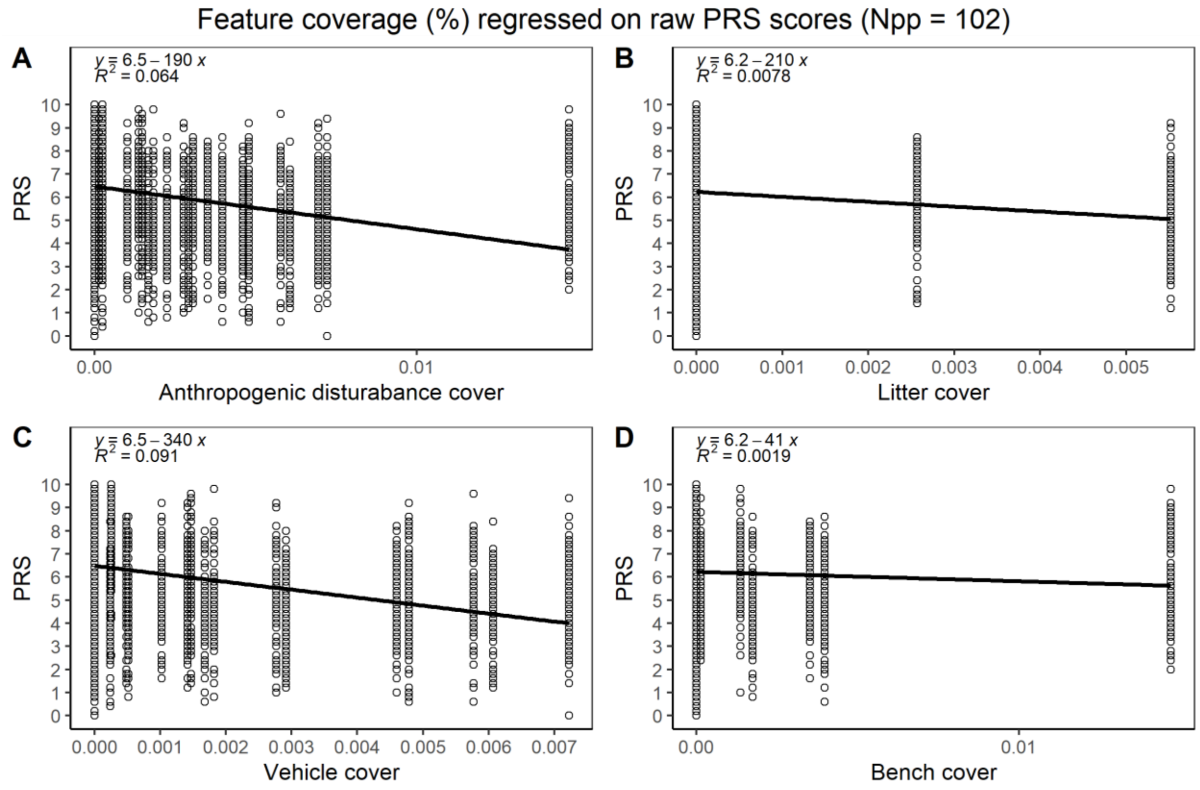

Figure S 32: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

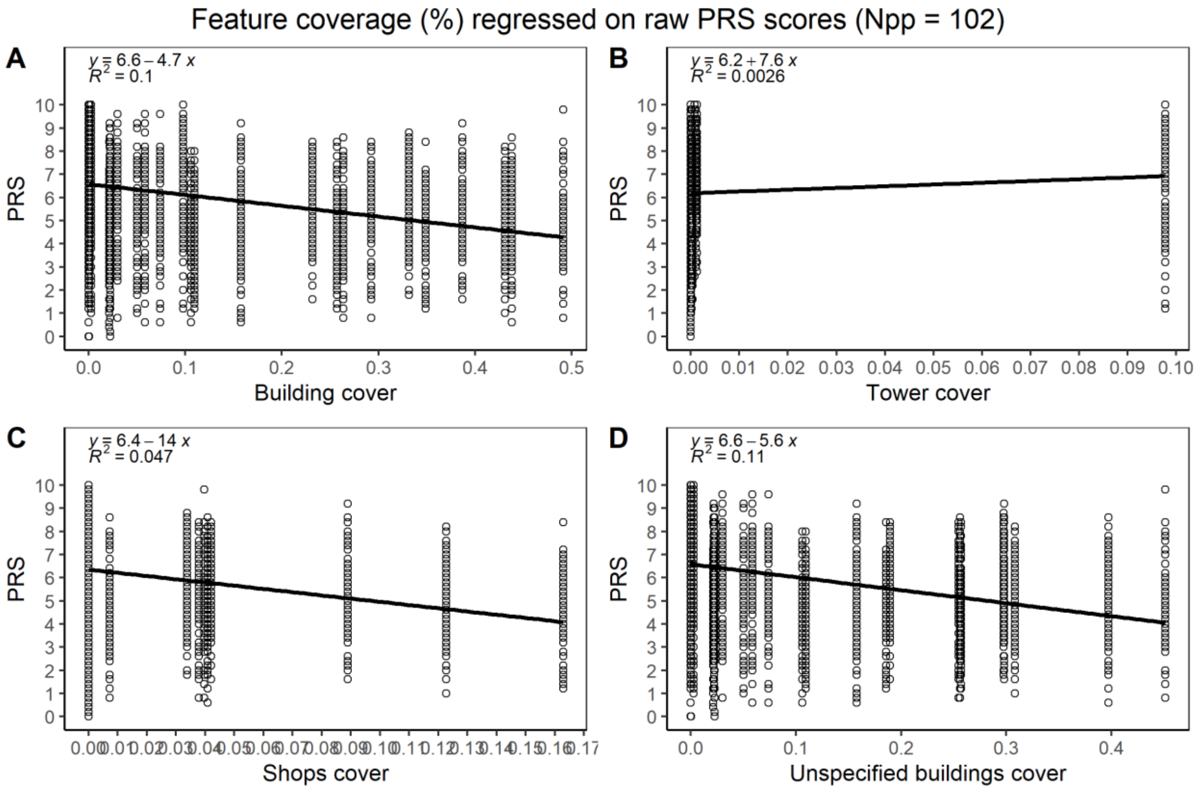

Figure S 33: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

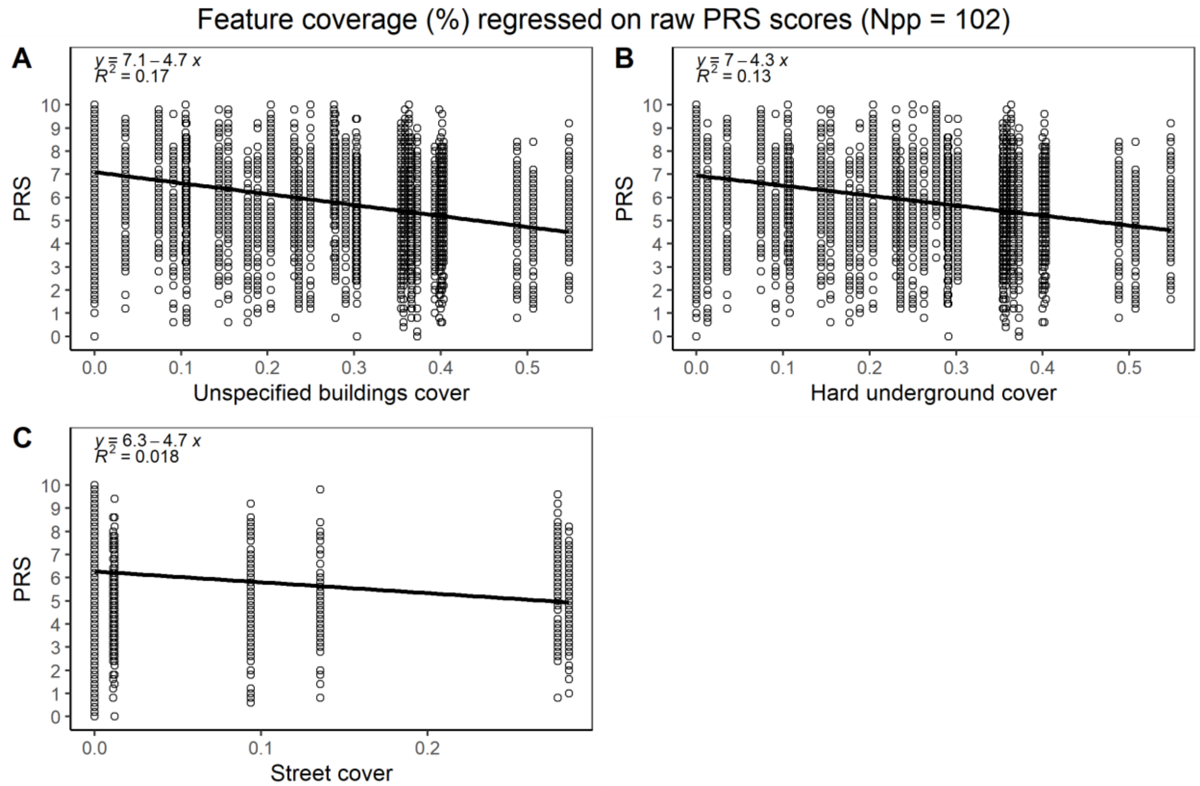

Figure S 34: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

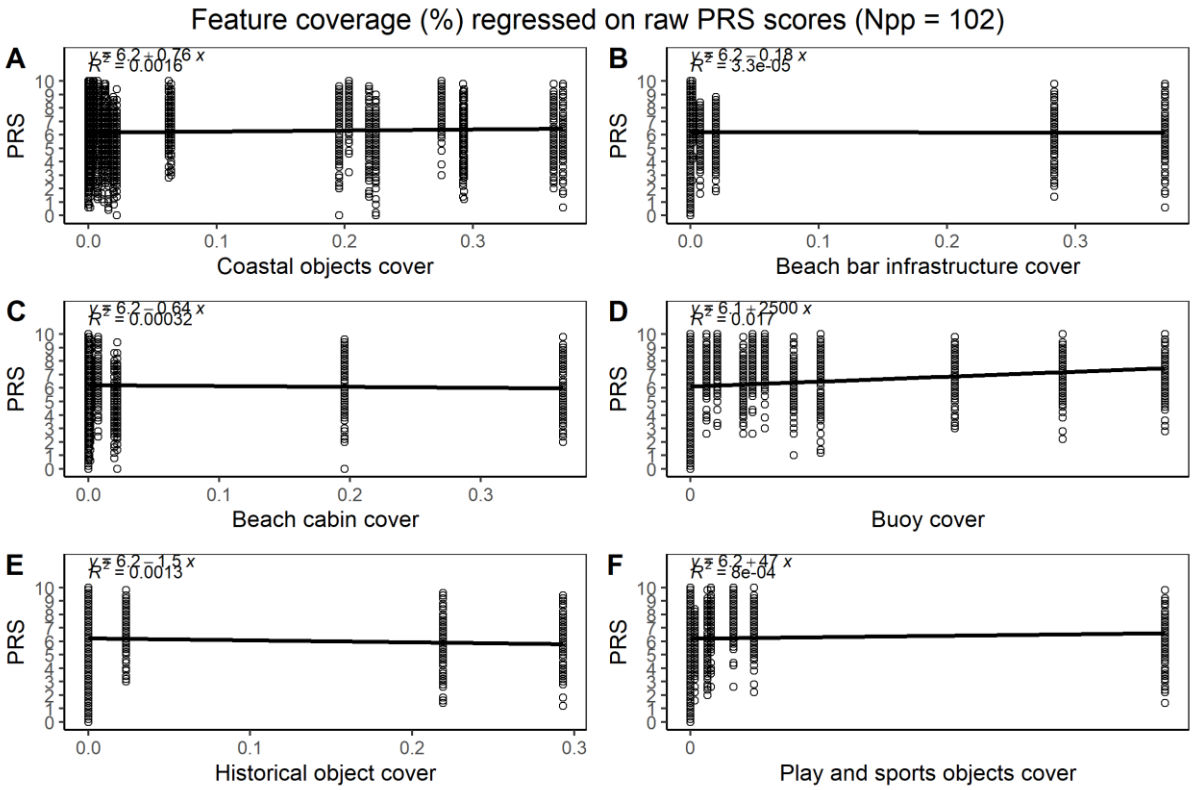

Figure S 35: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

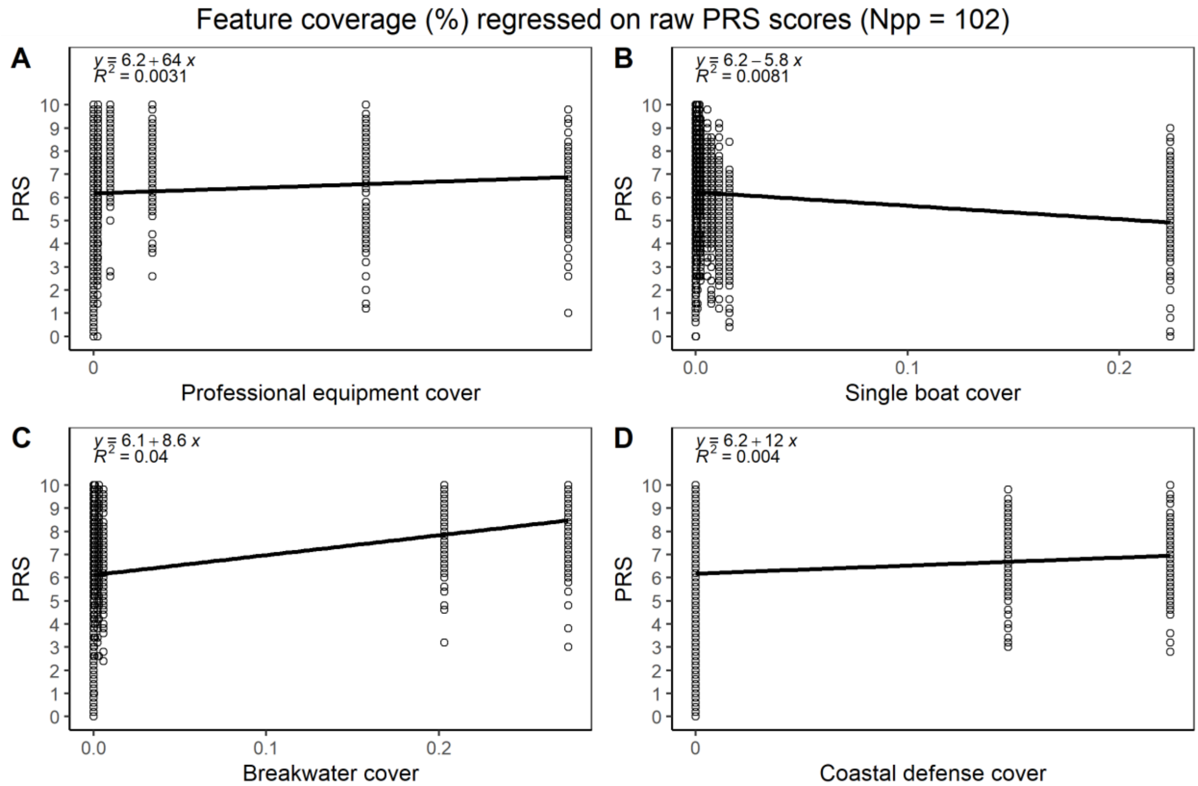

Figure S 36: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

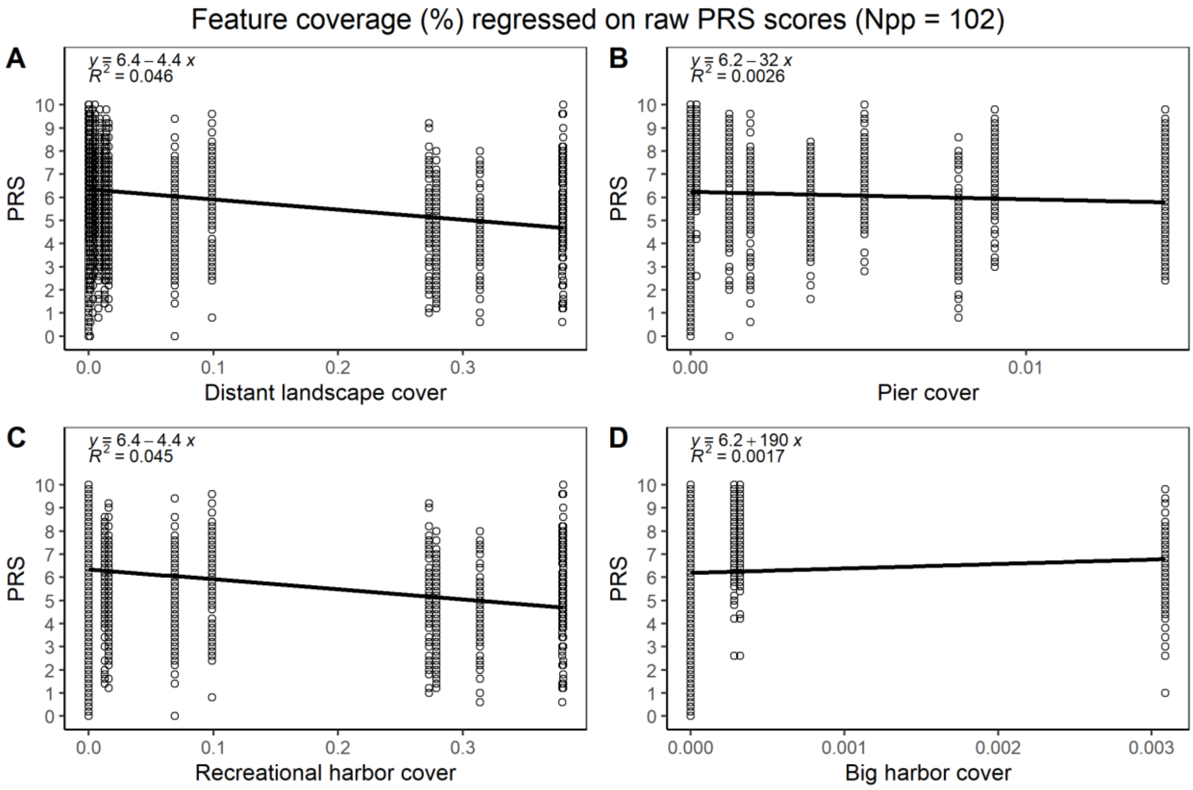

Figure S 37: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

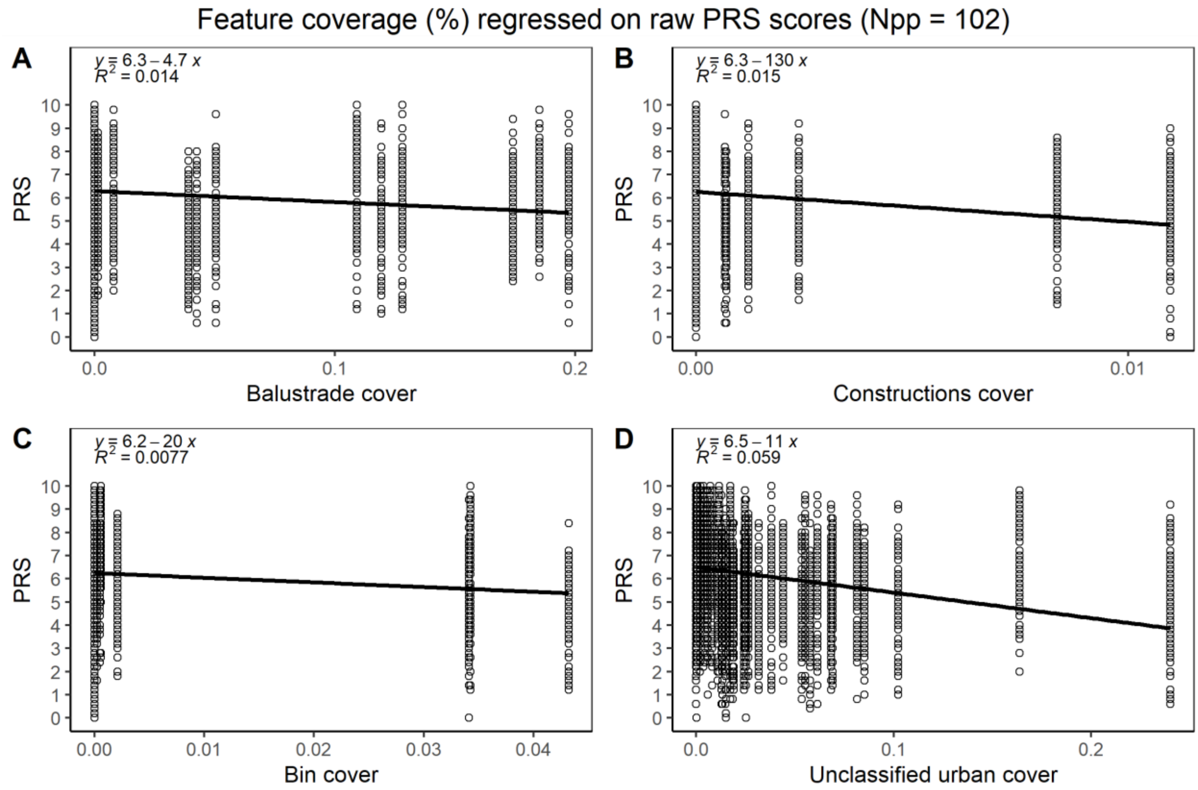

Figure S 38: The reported PRS values by the 102 included participants plotted against some of the picture content of 52 pictures. Linear model equation and explained variance (R^2) is also represented in the top left corner of each sub-plot.

Modelled estimates

Table S 23: Model estimates and model fit parameters of separate linear models (ANOVA) that regressed the picture content on PRS.
* Covariates in the models accounted for approximately 6% of the explained variation, which have been subtracted from the Added R^2marginal values for easier interpretation.

	Model estimates					Model fit parameters				
Component	B	SE	df	t-value	p-value (adjusted BH)	R^2 (marginal)	R^2 (conditional)	AIC	BIC	r
Natural	3.175	0.304	50	10.439	< 0.001	0.300	0.597	18191.514	18257.276	0.493
Vegetation	2.001	0.693	50	2.885	0.020	0.110	0.600	18241.006	18306.768	0.225
Landplant	0.101	0.971	50	0.104	0.935	0.061	0.601	18248.176	18313.938	0.009
Dune vegetation	3.882	1.080	50	3.595	0.004	0.132	0.600	18236.249	18302.011	0.270
Salt marsh vegetation	5.467	2.462	50	2.221	0.078	0.092	0.601	18241.529	18307.292	0.178
Flower box	-377.407	226.985	50	-1.663	0.207	0.079	0.601	18234.534	18300.296	-0.136
Water	2.302	1.549	50	1.486	0.255	0.076	0.601	18245.049	18310.811	0.122
Brackish water	33.271	15.372	50	2.164	0.085	0.091	0.601	18238.096	18303.858	0.174
Seawater	1.953	1.548	50	1.262	0.338	0.072	0.601	18245.656	18311.418	0.105
Still water	-0.377	2.154	50	-0.175	0.896	0.061	0.601	18246.563	18312.325	-0.015
Waves	4.146	2.360	50	1.757	0.188	0.081	0.601	18243.356	18309.119	0.143
Seawater on the beach	50.084	15.629	50	3.204	0.010	0.120	0.600	18233.104	18298.866	0.246
Sky	3.344	1.020	50	3.277	0.008	0.122	0.600	18238.165	18303.928	0.250
Blue sky	0.470	1.533	50	0.307	0.840	0.062	0.601	18247.178	18312.940	0.026
Delineated cumulus	3.392	1.477	50	2.296	0.069	0.094	0.601	18242.238	18308.000	0.184
Non-delineated cumulus	3.350	1.956	50	1.713	0.197	0.080	0.601	18243.878	18309.640	0.140

Stratus and cirrus	0.362	1.309	50	0.277	0.847	0.062	0.601	18247.512	18313.275	0.023
Natural underground	3.108	0.809	50	3.840	0.002	0.140	0.600	18235.371	18301.133	0.284
Sand underground	3.492	0.831	50	4.203	< 0.001	0.152	0.600	18233.067	18298.829	0.304
Grass underground	-9.280	7.168	50	-1.295	0.334	0.072	0.601	18242.508	18308.270	-0.107
Marine debris	15.099	12.079	50	1.250	0.338	0.071	0.601	18241.576	18307.338	0.104
Wildlife	929.756	1050.400	50	0.885	0.530	0.066	0.601	18233.422	18299.184	0.074
Urban	-3.263	0.308	50	-10.587	< 0.001	0.302	0.597	18190.499	18256.261	-0.495
Building	-4.670	1.019	50	-4.584	< 0.001	0.164	0.600	18230.198	18295.960	-0.324
Shops	-13.929	5.014	50	-2.778	0.025	0.107	0.600	18237.583	18303.345	-0.218
Unspecified building	-5.615	1.192	50	-4.709	< 0.001	0.168	0.599	18229.058	18294.820	-0.330
Tower	7.557	12.492	50	0.605	0.691	0.063	0.601	18242.706	18308.469	0.051
Anthropogenic disturbance	-185.315	55.713	50	-3.326	0.008	0.124	0.600	18229.893	18295.656	-0.253
Vehicle	-344.178	83.039	50	-4.145	< 0.001	0.150	0.600	18224.227	18289.989	-0.301
Litter	-212.280	200.540	50	-1.059	0.427	0.069	0.601	18236.396	18302.158	-0.088
Bench	-40.805	78.583	50	-0.519	0.747	0.063	0.601	18239.126	18304.888	-0.044
Coastal object	0.760	1.617	50	0.470	0.754	0.063	0.601	18246.943	18312.705	0.039
Beach bar infrastructure	-0.182	2.655	50	-0.069	0.946	0.061	0.601	18246.171	18311.933	-0.006
Beach cabin	-0.637	2.999	50	-0.212	0.883	0.061	0.601	18245.886	18311.648	-0.018
Buoy	2519.649	1599.077	50	1.576	0.230	0.077	0.601	18230.903	18296.665	0.129
Historical object	-1.463	3.374	50	-0.434	0.768	0.062	0.601	18245.505	18311.267	-0.036
Play and sports objects	46.881	139.678	50	0.336	0.833	0.062	0.601	18238.135	18303.897	0.028
Single boat	-5.832	5.406	50	-1.079	0.427	0.069	0.601	18243.580	18309.342	-0.090
Breakwater	8.585	3.413	50	2.515	0.042	0.100	0.601	18239.597	18305.359	0.199

Coastal defense	12.467	16.544	50	0.754	0.618	0.065	0.601	18241.941	18307.703	0.063
Professional equipment	64.272	97.250	50	0.661	0.678	0.064	0.601	18238.530	18304.293	0.055
Urban underground	-4.729	0.711	50	-6.651	< 0.001	0.224	0.599	18216.486	18282.248	-0.408
Street	-4.681	2.837	50	-1.650	0.207	0.079	0.601	18243.339	18309.102	-0.135
Hard underground	-4.313	0.778	50	-5.542	< 0.001	0.193	0.599	18224.206	18289.968	-0.367
Distant landscape	-4.431	1.623	50	-2.730	0.027	0.106	0.600	18240.076	18305.838	-0.214
Pier	-31.888	52.674	50	-0.605	0.691	0.063	0.601	18239.828	18305.590	-0.051
Recreational harbor	-4.367	1.620	50	-2.696	0.028	0.105	0.600	18240.242	18306.004	-0.212
Big harbor	194.221	393.615	50	0.493	0.751	0.063	0.601	18235.930	18301.692	0.041
Bin	-20.065	19.087	50	-1.051	0.427	0.068	0.601	18241.116	18306.878	-0.087
Balustrade	-4.747	3.288	50	-1.444	0.265	0.075	0.601	18243.665	18309.427	-0.119
Constructions	-128.835	86.897	50	-1.483	0.255	0.076	0.601	18237.005	18302.767	-0.122
Unclassified urban	-10.991	3.492	50	-3.147	0.011	0.118	0.600	18236.409	18302.171	-0.242
People	-19.684	9.593	50	-2.052	0.105	0.088	0.601	18239.483	18305.246	-0.166

3. Supplementary information for Chapter IV

3.1. Methods

3.1.1. Recruitment

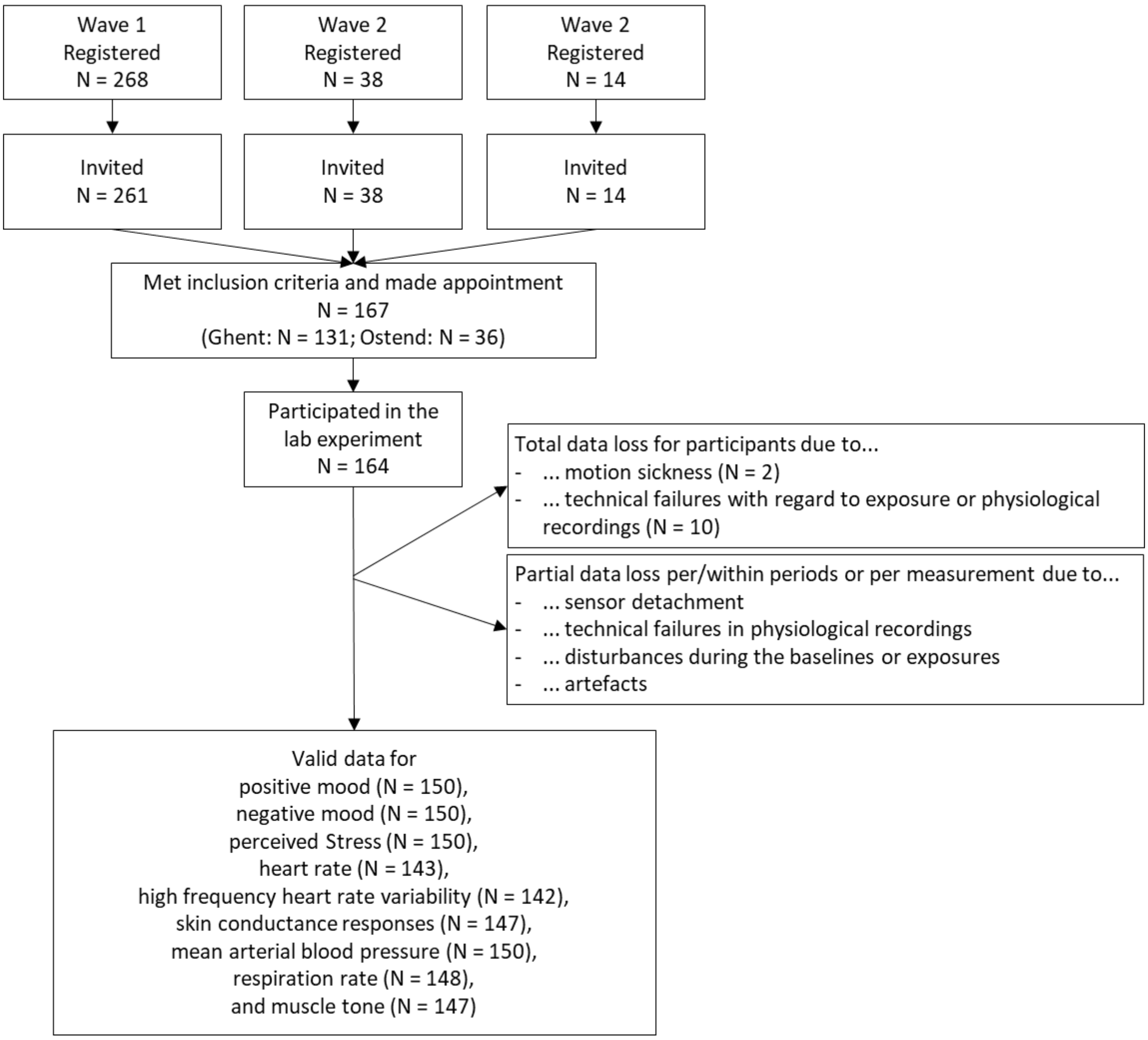

Figure S 39: Flow-chart of the recruitment and data.

3.1.2. Virtual reality exposures

Table S 24: Description of the eight scenes in each exposure

		Scenes							
Exposures		1	2	3	4	5	6	7	8
Beaches	**Coastal proximity**	Mid	Mid	Mid	Near shore	Near shore	Near shore	Near dunes	Near dunes
	Adjacent settings	Dunes	Dunes	Town	Town	Dunes	Dunes	Dunes	Dunes
	Location	Koksijde (8670)	De Haan (8420)	Wenduine (8420)	Wenduine (8420)	Koksijde (8670)	De Haan (8420)	De Haan (8420)	De Haan (8420)
Green spaces	**Type**	Rural farmland	Rural farmland	Deciduous forest	Deciduous forest	Semi-urban park	Urban park	Mixed forest	Open forest area
	Undergro und	Street	Street	Asphalted	Asphalted	Grass	Grass	Unpaved	Unpaved
	Location	Grote Noordstraat (Gits 8830)	Bosdreef (Torhout 8820)	Groenhove (Torhout, 8820)	Groenhove (Torhout, 8820)	Bataviawijk (Roeselare 8800)	Noordhof (Roeselare 8800)	Groenhove (Torhout, 8820)	Groenhove (Torhout, 8820)
Urban spaces	**Type**	Square	Square	Shopping street	Shopping street	Square	Square	Calm street	Calm street
	Location	Grote Markt (Roeselare 8800)	Station (Roeselare 8800)	Noordstraat (Roeselare 8800)	Ooststraat (Roeselare 8800)	De Munt (Roeselare 8800)	Grote Markt (Roeselare 8800)	Motestraat (Roeselare 8800)	Bataviawijk (Roeselare 8800)

3.1.3. Physiological measurements

The signals from participants 1 to 41 were retrieved at 512 samples per second (cable connection), and those from participants 42 to 164 at 256 samples per second (Bluetooth connection). The treatments were evenly spread over the participants that received higher and lower sample rates (Table 6), and the performed analyses on the signals were done with respect to the Shannon sampling theory (i.e., frequencies of interest should be sampled at twice the frequency; Tan & Jiang, 2019) and with respect to previous guidelines (Larivière et al., 2005).

HF-HRV

The ECG analyzer applied a 1 Hz high pass filter and 50 Hz lowpass filter to the signal, detected the R-peaks, derived the heart rate (in beats per minute, BPM), and calculated the inter-beat-intervals (IBI) that formed the basis for the heart rate variability analyses. During this stage, artefacts were manually corrected to ensure that the R peaks were detected correctly and to disregard incomplete PQRST complexes. Ectopic beats and other natural variations in heart beats which were not measurement artefacts were not excluded. Then, the heart rate variability analyzer applied smoothing to the IBI data with a lambda value of 500 and IBI resampling frequency of 4 HZ (equals an approximate high pass cutoff frequency of 0.04 Hz; (Tarvainen et al., 2002)). It also detrended the IBI data before the frequency-domain indices (e.g., HF-HRV) using the Lomb-Scargle method with power spectral density calculation and smoothing with a loess filter on the periodogram (Sjak-Shie, 2019).

SCR

Both of these fingers were carefully rinsed with water and dried prior application of the sensors to remove excessive dirt and sweat. The data was downsampled to 64 Hz, manually checked for artefacts, and a continuous decomposition analysis (CDA, (Benedek & Kaernbach, 2010)) was applied to distinguish the phasic skin conductance responses from the tonic skin conductance level.

MAP

The signal was filtered with a low-pass filter at 50 Hz, and the systolic peaks and diastolic valleys were derived in the PhysioDataToolbox (v0.5.0; Sjak-Shie, 2019) by tweaking with the calibration settings. The signal with detected peaks and valleys was manually checked for correctness and to exclude measurement artefacts.

Breathing rate

This respiration belt contained a sensor that measured the stretch on the belt that was caused by the breathing. The signal was analyzed in BioTrace+ (version 2018A1, Mind Media B.V., 2020), in which the signal was downsampled to 32 samples per seconds before a general signal processing computation calculated the respiration rate (unit: breaths per minute) per time unit.

Muscle tone

The two electrodes were attached with Ag-Cl pre-gelled pads (30 x 24 mm Kendall H124SG ECG electrodes, Cardinal health, 2020) against each other so that the distance between the two electrodes was always 30mm. An EMG analyzer applied a high-pass FIR filter, low-pass FIR filter, and notch filter at 27 Hz, 500 Hz, and 50 Hz, respectively, and rectification on the signal. The rectified signal was smoothed with a Boxcar filter according to (van Boxtel, 2010) with a size of 100 ms. The signal was manually checked for measurement artefacts.

3.1.4. Self-reported measurements

Positive and negative mood

The scale questions how the participants experienced 10 positive and 10 negative mood states at the moment of administration. The participants had to give their score on five-point Likert scales ranging from 'very little or not', over 'a little', 'moderately', and 'quite a bit', to 'a lot'. The scores were labelled from zero to four and averaged per positive or negative mood. The positive mood states were administered in the following order: interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, and active. The negative mood states were administered after the positive mood states and in the following order: upset, distressed, guilty, anxious, hostile, jittery, ashamed, nervous, restless, and fearful.

3.2. Analyses

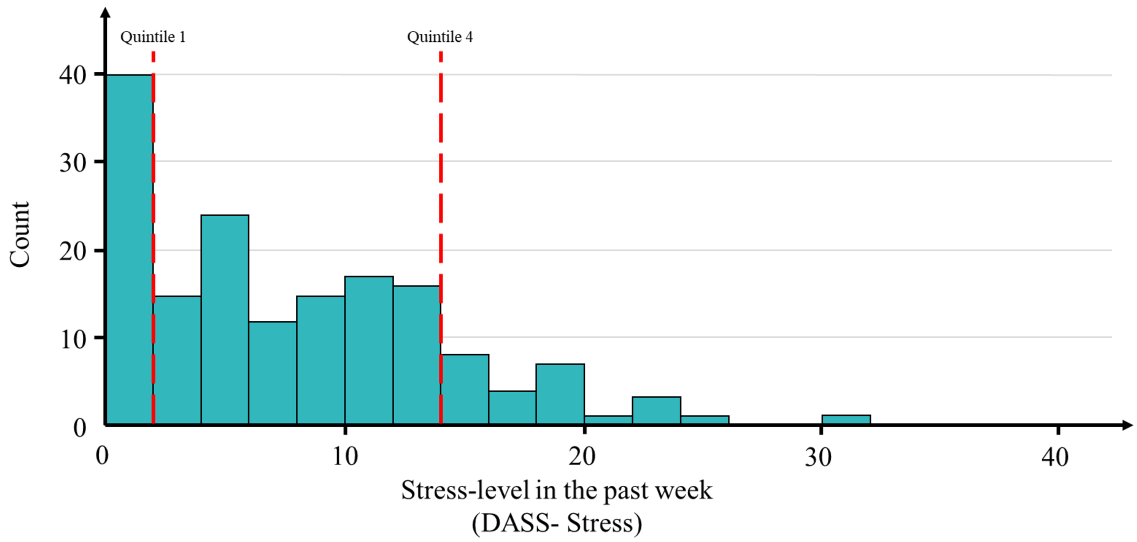

Figure S 40: Histogram of DASS-Stress. Red vertical lines indicate the first and fifth quintile. The values represented by these lines were used for the computing and plotting the estimated marginal means.

3.3. Results

3.3.1. ANOVA-estimates

Table 17: ANOVA-estimates of the model for each outcome with F-values, unadjusted p-values and adjusted p-values according to the procedure of Benjamini-Hochberg (Benjamini & Hochberg, 1995).

Outcome	Estimate	F	p	p (adjusted BH)
Positive mood	Environment (Beach - ref, Green, Urban)	3.251	0.040	0.106
Positive mood	Time (Pre - ref, Post)	1.609	0.373	0.586
Positive mood	DASS-Stress	15.369	≤0.001	0.001
Positive mood	Environment*Time	0.311	0.733	0.880
Positive mood	Environment*DASS-Stress	0.882	0.415	0.637
Positive mood	Time*DASS-Stress	2.456	0.118	0.244
Positive mood	Environment*Time*DASS-Stress	4.754	0.009	0.038
Negative mood (sqrt)	Environment (Beach - ref, Green, Urban)	0.606	0.546	0.723
Negative mood (sqrt)	Time (Pre - ref, Post)	1.637	0.301	0.497
Negative mood (sqrt)	DASS-Stress	74.153	≤0.001	≤0.001
Negative mood (sqrt)	Environment*Time	7.266	0.001	0.004
Negative mood (sqrt)	Environment*DASS-Stress	0.199	0.819	0.901
Negative mood (sqrt)	Time*DASS-Stress	0.147	0.702	0.858
Negative mood (sqrt)	Environment*Time*DASS-Stress	4.307	0.014	0.052
Perceived stress	Environment (Beach - ref, Green, Urban)	0.217	0.805	0.901
Perceived stress	Time (Pre - ref, Post)	0.002	0.967	0.998

Perceived stress	DASS-Stress	18.460	≤0.001	≤0.001
Perceived stress	Environment*Time	7.424	0.001	0.004
Perceived stress	Environment*DASS-Stress	0.776	0.461	0.676
Perceived stress	Time*DASS-Stress	0.078	0.781	0.888
Perceived stress	Environment*Time*DASS-Stress	3.057	0.048	0.123
Perceived quality of the environment for relaxation	Environment (Beach - ref, Green, Urban)	41.062	≤0.001	≤0.001
Perceived quality of the environment for relaxation	DASS-Stress	4.274	0.040	0.106
Perceived quality of the environment for relaxation	Environment*DASS-Stress	0.087	0.917	0.960
HF-HRV (log10)	Environment (Beach - ref, Green, Urban)	2.798	0.061	0.150
HF-HRV (log10)	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	6.721	≤0.001	≤0.001
HF-HRV (log10)	DASS-Stress	3.031	0.084	0.191
HF-HRV (log10)	Environment*2-minute section	1.174	0.274	0.476
HF-HRV (log10)	Environment*DASS-Stress	4.645	0.010	0.038
HF-HRV (log10)	2-minute section*DASS-Stress	0.760	0.654	0.814
HF-HRV (log10)	Environment*2-minute section*DASS-Stress	1.151	0.296	0.497
SCR (sqrt)	Environment (Beach - ref, Green, Urban)	21.267	≤0.001	≤0.001
SCR (sqrt)	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	7.041	≤0.001	≤0.001
SCR (sqrt)	DASS-Stress	4.644	0.033	0.098
SCR (sqrt)	Environment*2-minute section	0.932	0.538	0.723
SCR (sqrt)	Environment*DASS-Stress	1.609	0.200	0.378

SCR (sqrt)	2-minute section*DASS-Stress	1.294	0.235	0.431
SCR (sqrt)	Environment*2-minute section*DASS-Stress	1.300	0.177	0.344
Heart rate	Environment (Beach - ref, Green, Urban)	0.657	0.519	0.723
Heart rate	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	15.715	≤0.001	≤0.001
Heart rate	DASS-Stress	5.858	0.017	0.058
Heart rate	Environment*2-minute section	0.673	0.840	0.909
Heart rate	Environment*DASS-Stress	2.192	0.112	0.244
Heart rate	2-minute section*DASS-Stress	1.438	0.166	0.332
Heart rate	Environment*2-minute section*DASS-Stress	0.865	0.623	0.790
Breathing rate	Environment (Beach - ref, Green, Urban)	6.690	0.001	0.006
Breathing rate	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	16.934	≤0.001	≤0.001
Breathing rate	DASS-Stress	4.345	0.039	0.106
Breathing rate	Environment*2-minute section	1.707	0.032	0.098
Breathing rate	Environment*DASS-Stress	0.113	0.893	0.951
Breathing rate	2-minute section*DASS-Stress	1.004	0.434	0.651
Breathing rate	Environment*2-minute section*DASS-Stress	0.928	0.544	0.723
Muscle tone (sqrt)	Environment (Beach - ref, Green, Urban)	11.183	≤0.001	≤0.001
Muscle tone (sqrt)	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	0.799	0.617	0.790
Muscle tone (sqrt)	DASS-Stress	0.364	0.547	0.723
Muscle tone (sqrt)	Environment*2-minute section	1.076	0.370	0.586
Muscle tone (sqrt)	Environment*DASS-Stress	26.274	≤0.001	≤0.001

Muscle tone (sqrt)	2-minute section*DASS-Stress	0.268	0.983	0.998
Muscle tone (sqrt)	Environment*2-minute section*DASS-Stress	1.530	0.071	0.167
Mean arterial blood pressure	Environment (Beach - ref, Green, Urban)	2.135	0.118	0.244
Mean arterial blood pressure	2-minute section (b1 - ref, b2, e1, e1, e2, ..., e7, e8)	2.418	0.010	0.038
Mean arterial blood pressure	DASS-Stress	5.441	0.021	0.069
Mean arterial blood pressure	Environment*2-minute section	0.740	0.772	0.888
Mean arterial blood pressure	Environment*DASS-Stress	1.386	0.250	0.447
Mean arterial blood pressure	2-minute section*DASS-Stress	0.638	0.765	0.888
Mean arterial blood pressure	Environment*2-minute section*DASS-Stress	0.267	0.999	0.999

3.3.2. B-estimates

Available at B-Estimates_2022-09-05.xlsx in the online version of the manuscript.

3.3.3. Estimated Marginal Means

Available at Emmeans_2022-09-05.xlsx in the online version of the manuscript.

3.3.4. Differences between Estimated Marginal Means

Available at Emmeans.diff_2022-09-05.xlsx in the online version of the manuscript.

4. Supplementary information for Chapter VI

4.1. Supplementary figures

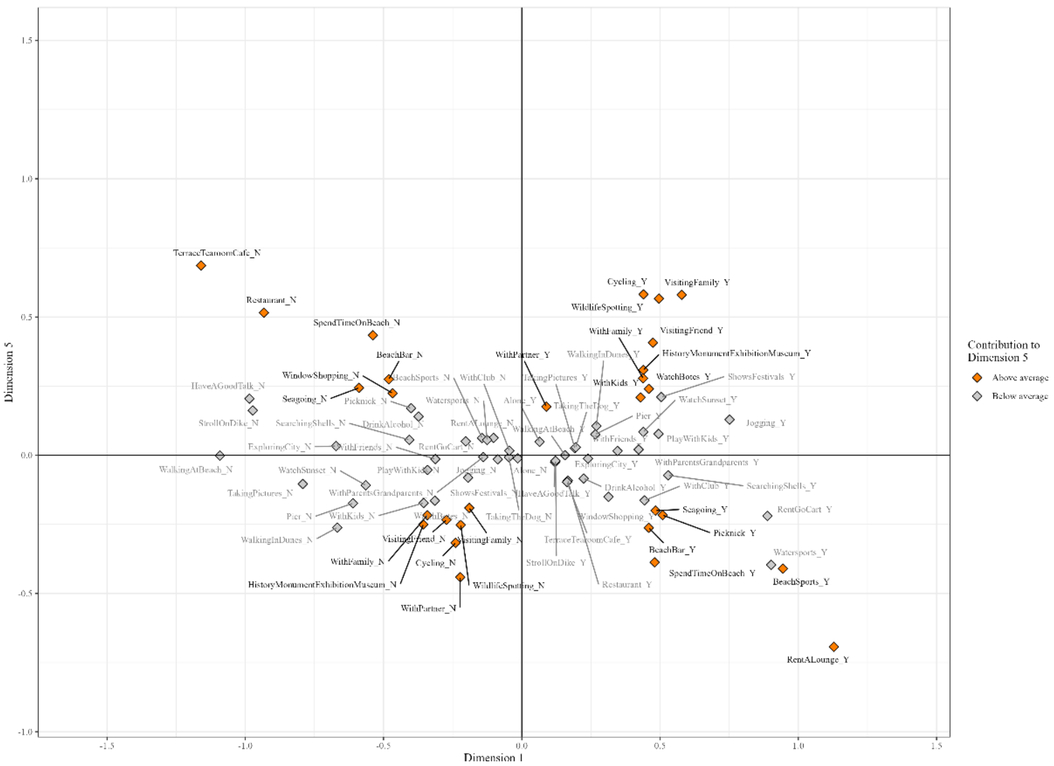

Figure S 41: Contributions of main categories to dimension five.

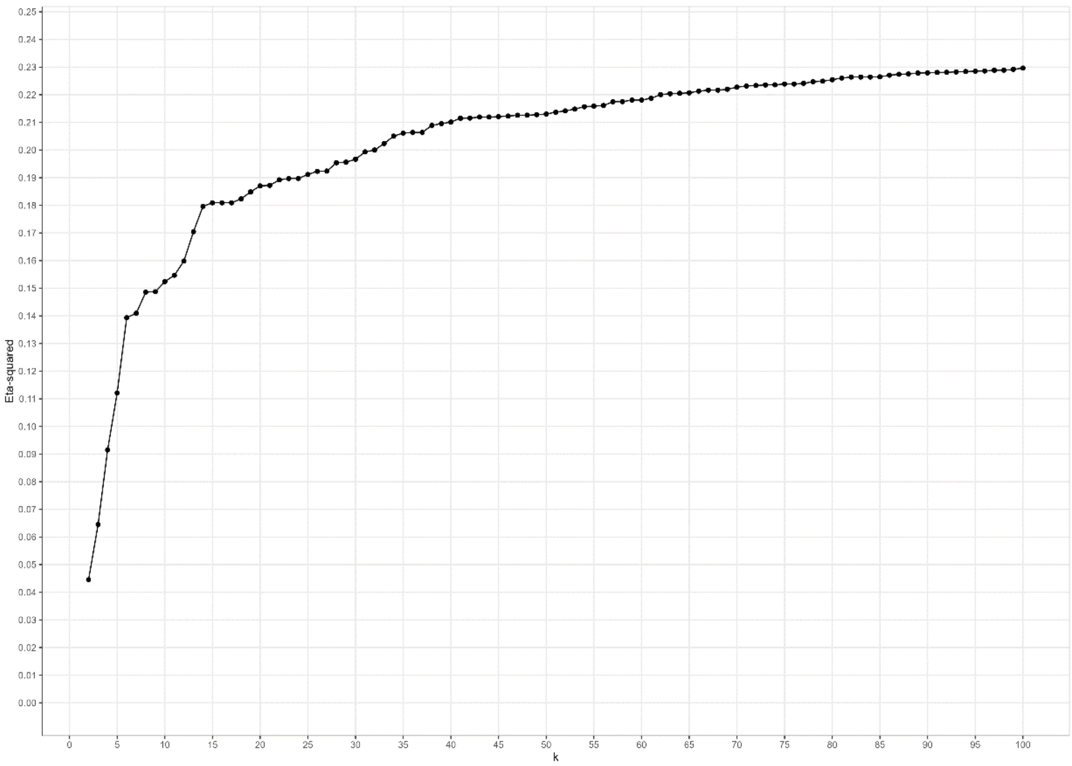

Figure S 42: Plot depicting the drop in η² (eta-squared; y-axis) with decreasing number of clusters (k; x-axis; right to left) from the AHC analysis.

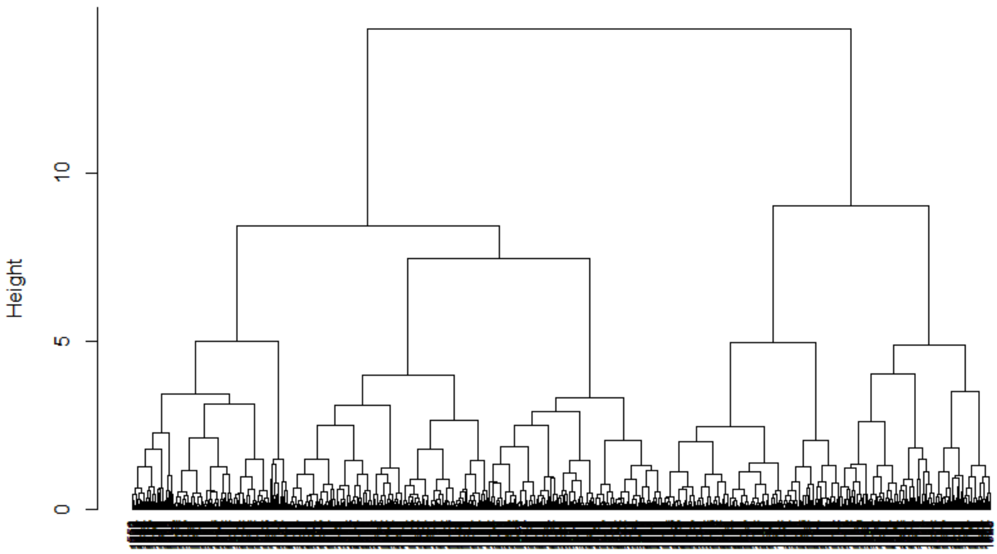

Figure S 43: Dendrogram from the AHC analysis.

4.2. Supplementary tables

Table S 25: Contributions of the variables and categories to either side of dimension 1. Only the categories that contribute above average are depicted.

		Category		Contribution	
Variable	Contribution	Left	Right	Left	Right
Seagoing	5.46	No	Yes	3	2.46
SpendTimeOnBeach	4.96	No	Yes	2.62	2.34
WatchSunset	4.75	No	Yes	2.67	2.08
BeachBar	4.23	No	Yes	2.16	2.07
SearchingShells	4.13	No	Yes	1.79	2.33
Picknick	3.91	No	Yes	1.72	2.19
TerraceTearoomCafe	3.64	No		3.19	
WalkingInDunes	3.45	No		2.46	
RentGoCart	3.45		Yes		2.81
WalkingAtBeach	3.27	No		2.86	
PlayWithKids	3.23	No	Yes	1.32	1.91
Pier	3.11	No		2.17	
ExploringCity	3.08	No		2.27	
HistoryMonumentExhibitionMuseum	3	No	Yes	1.34	1.66
Restaurant	2.97	No		2.52	
WithKids	2.92	No	Yes	1.32	1.6
TakingPictures	2.91	No		2.34	
WithFamily	2.87		Yes		1.61
WindowShopping	2.81	No		1.68	
WatchBotes	2.77		Yes		1.64
BeachSports	2.6		Yes		2.26
VisitingFriend	2.48		Yes		1.57
HaveAGoodTalk	2.28	No		2.03	
StrollOnDike	2.27	No		2.02	
RentALounge	2.21		Yes		2.02
Watersports	2.17		Yes		1.9
VisitingFamily	2.1		Yes		1.58
WildlifeSpotting	2.1		Yes		1.45
ShowsFestivals	1.88		Yes		1.36

Table S 26: Contributions of the variables and categories to either side of dimension 2. Only the categories that contribute above average are depicted.

		Category		Contribution	
Variable	Contribution	Bottom	Top	Bottom	Top
Restaurant	10.78	Yes	No	1.63	9.15
TerraceTearoomCafe	9.3		No		8.15
ExploringCity	8.1	Yes	No	2.13	5.97
PlayWithKids	7.94	No	Yes	3.24	4.7
DrinkAlcohol	5.06	Yes	No	1.9	3.17
WithKids	4.79	No	Yes	2.17	2.62
StrollOnDike	4.73		No		4.2
SearchingShells	4.67	No	Yes	2.03	2.64
Watersports	4.67		Yes		4.1
WindowShopping	4.44	Yes	No	1.78	2.66
BeachSports	4.16		Yes		3.61
Seagoing	4.15	No	Yes	2.28	1.87
WithParentsGrandparents	3.42		Yes		2.57
SpendTimeOnBeach	2.82	No	Yes	1.49	1.33
WatchBotes	2.75	Yes		1.63	
HistoryMonumentExhibitionMuseum	2.49	Yes		1.38	
HaveAGoodTalk	2.37		No		2.11
RentGoCart	2.37		Yes		1.93
Jogging	2.19		Yes		1.97
Pier	1.99		No		1.38

Table S 27: Contributions of the variables and categories to either side of dimension 3. Only the categories that contribute above average are depicted.

		Category		Contribution	
Variable	Contribution	Bottom	Top	Bottom	Top
VisitingFriend	10.74	No	Yes	3.92	6.82
WithFriends	10.67	No	Yes	5.07	5.61
WithKids	7.47	Yes	No	4.09	3.38
WithPartner	7.27	Yes	No	2.07	5.2
WithClub	6.6		Yes		5.99
ShowsFestivals	6.34	No	Yes	1.76	4.58
PlayWithKids	6.29	Yes	No	3.73	2.57
Alone	6.16		Yes		5.01
WalkingAtBeach	5.3		No		4.63
SearchingShells	4.43	Yes	No	2.51	1.93
RentALounge	4.07		Yes		3.73
VisitingFamily	3.35		Yes		2.52
Watersports	2.73		Yes		2.4
BeachSports	2.7		Yes		2.34
TakingPictures	2.17		No		1.74
WalkingInDunes	2.14		No		1.52
Jogging	1.98		Yes		1.77

Table S 28: Contributions of the variables and categories to either side of dimension 4. Only the categories that contribute above average are depicted.

		Category		Contribution	
Variable	Contribution	Bottom	Top	Bottom	Top
WildlifeSpotting	8.4	No	Yes	2.59	5.81
VisitingFamily	7.75	Yes	No	5.83	1.92
Alone	7.61	No	Yes	1.42	6.19
WithKids	7.58	Yes	No	4.15	3.43
WithFamily	6.45	Yes	No	3.62	2.82
PlayWithKids	5.63	Yes	No	3.33	2.3
WithPartner	5.59	Yes	No	1.59	4
WalkingAtBeach	5.52	No		4.83	
WalkingInDunes	5.47	No	Yes	3.9	1.58
WatchSunset	4.8	No	Yes	2.7	2.1
Restaurant	4.21		No		3.57
TerraceTearoomCafe	3.76		No		3.3
Pier	2.87	No		2	
HistoryMonumentExhibitionMuseum	2.67		Yes		1.47
VisitingFriend	2.62	Yes		1.67	
DrinkAlcohol	2.55		No		1.59
WithParentsGrandparents	2.22	Yes		1.67	
WithClub	2.06		Yes		1.87
HaveAGoodTalk	1.76		No		1.57

Table S 29: The sample and cluster frequencies, and the ratio between them, of the main and supplementary categories. Only the categories for which the cluster frequency differs significantly from the sample frequency based on Chi-Square tests are listed. Solid lines separate the table between clusters, dashed lines separate the clusters per categories that are overrepresented (ratio > 1) and underrepresented (ratio < 1).
Abbreviations: M = 'Main variable', S = Supplementary variable.

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
1	M	Activities	RentALounge_Y	0.083	0.274	3.306
1	S	Activities	Mountainbiking_Y	0.043	0.131	3.041
1	M	Activities	BeachSports_Y	0.132	0.388	2.938
1	M	Activities	Watersports_Y	0.122	0.329	2.695
1	M	Activities	RentGoCart_Y	0.186	0.494	2.656
1	M	Activities	Jogging_Y	0.104	0.270	2.604
1	M	Activities	VisitingFamily_Y	0.247	0.624	2.525
1	S	Demography	CoastalHolidayResidence_Y	0.101	0.236	2.348
1	S	Experiences	FeelingAnxious_Y	0.058	0.127	2.197
1	M	Activities	PlayWithKids_Y	0.408	0.835	2.048
1	M	Social company	WithParentsGrandparents_Y	0.248	0.506	2.041
1	M	Activities	VisitingFriend_Y	0.365	0.734	2.012
1	M	Social company	WithFamily_Y	0.438	0.848	1.937
1	S	SES	Employment_Coast_Y	0.082	0.156	1.900
1	M	Social company	WithKids_Y	0.452	0.857	1.893
1	S	Demography	<5km	0.071	0.122	1.732
1	M	Activities	SearchingShells_Y	0.435	0.730	1.679
1	S	Experiences	EnjoyingSummerCrowding_Y	0.366	0.603	1.650
1	M	Social company	WithFriends_Y	0.475	0.776	1.636
1	M	Activities	Cycling_Y	0.353	0.570	1.616
1	M	Activities	ShowsFestivals_Y	0.278	0.447	1.609
1	M	Activities	Picknick_Y	0.440	0.705	1.601
1	M	Activities	BeachBar_Y	0.512	0.806	1.576
1	M	Activities	Seagoing_Y	0.549	0.861	1.567
1	M	Activities	SpendTimeOnBeach_Y	0.528	0.802	1.517
1	S	Visits	DaysAtCoast_>8	0.272	0.409	1.505
1	S	Visits	StayVisits_Winter_Y	0.203	0.300	1.477
1	S	Experiences	BeingBored_Y	0.122	0.177	1.451
1	S	Visits	StayVisits_Summer_Y	0.359	0.511	1.420
1	M	Activities	TakingTheDog_Y	0.193	0.270	1.401
1	S	Experiences	EnjoyingSandToes_Y	0.558	0.759	1.362
1	S	Experiences	ProblemSolving_Y	0.440	0.599	1.361
1	M	Activities	WatchBotes_Y	0.406	0.549	1.350
1	S	Visits	StayVisits_Spring_Y	0.263	0.354	1.345
1	M	Activities	WildlifeSpotting_Y	0.308	0.409	1.329
1	S	Demography	Household_>1	0.531	0.700	1.320
1	M	Activities	DrinkAlcohol_Y	0.625	0.823	1.316
1	S	Demography	40-49y	0.202	0.266	1.316
1	S	Visits	StayVisits_Fall_Y	0.185	0.241	1.299
1	M	Activities	WatchSunset_Y	0.562	0.730	1.298
1	M	Activities	WindowShopping_Y	0.598	0.759	1.269
1	S	Health	SF36MH_Q1-Q2	0.243	0.308	1.269
1	M	Activities	HistoryMonumentExhibitionMuseum_Y	0.448	0.553	1.234
1	S	Demography	SocialSupport_>5	0.332	0.409	1.234
1	S	Experiences	GainingSelfConfidence_Y	0.596	0.730	1.225
1	S	Demography	VisitsKid_>5	0.517	0.624	1.208
1	M	Activities	WalkingInDunes_Y	0.712	0.844	1.185
1	S	Experiences	FeelingAtHome_Y	0.787	0.932	1.184
1	S	Experiences	BeingInAwe_Y	0.735	0.869	1.183
1	S	Experiences	FeelingActive_Y	0.784	0.916	1.168
1	M	Activities	Pier_Y	0.697	0.810	1.163
1	S	SES	Employment_Active	0.602	0.696	1.156
1	S	Experiences	LosingTrackOfTime_Y	0.780	0.895	1.146
1	M	Social company	WithPartner_Y	0.715	0.819	1.145
1	S	Experiences	FeelingCompatible_Y	0.793	0.907	1.143
1	M	Activities	ExploringCity_Y	0.737	0.835	1.133

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
1	M	Activities	Restaurant_Y	0.849	0.954	1.124
1	M	Activities	TerraceTearoomCafe_Y	0.876	0.979	1.117
1	S	Experiences	RecallingMemories_Y	0.666	0.743	1.115
1	S	Experiences	SituateFeelingsThoughts_Y	0.742	0.827	1.115
1	M	Activities	TakingPictures_Y	0.805	0.895	1.111
1	S	Experiences	BeingFascinated_Y	0.827	0.907	1.097
1	S	Demography	Household_Partner_N	0.627	0.688	1.096
1	S	Experiences	HavingHolidayVibes_Y	0.887	0.970	1.094
1	M	Activities	HaveAGoodTalk_Y	0.891	0.970	1.089
1	S	Experiences	FeelingPhysicalRest_Y	0.871	0.945	1.085
1	S	Experiences	ConnectingWithNature_Y	0.835	0.903	1.082
1	S	Experiences	EnjoyingExtent_Y	0.825	0.890	1.079
1	S	Experiences	FeelingFree_Y	0.899	0.966	1.074
1	M	Activities	WalkingAtBeach_Y	0.875	0.932	1.066
1	S	Experiences	EnjoyingSoundOfWaves_Y	0.899	0.949	1.056
1	S	Experiences	BeingBored_N	0.878	0.823	0.937
1	S	Visits	StayVisits_Fall_N	0.815	0.759	0.932
1	S	Experiences	FeelingAnxious_N	0.942	0.873	0.927
1	S	SES	Employment_Coast_N	0.918	0.844	0.919
1	S	Activities	Mountainbiking_N	0.957	0.869	0.908
1	M	Activities	TakingTheDog_N	0.807	0.730	0.904
1	S	Visits	StayVisits_Winter_N	0.797	0.700	0.879
1	S	Visits	StayVisits_Spring_N	0.737	0.646	0.876
1	M	Activities	WildlifeSpotting_N	0.692	0.591	0.854
1	S	Demography	CoastalHolidayResidence_N	0.899	0.764	0.849
1	S	Demography	Household_Partner_Y	0.373	0.312	0.838
1	M	Activities	Jogging_N	0.896	0.730	0.814
1	M	Activities	HistoryMonumentExhibitionMuseum_N	0.552	0.447	0.810
1	M	Activities	RentALounge_N	0.917	0.726	0.791
1	S	Experiences	RecallingMemories_N	0.334	0.257	0.770
1	M	Activities	ShowsFestivals_N	0.722	0.553	0.766
1	M	Activities	Watersports_N	0.878	0.671	0.764
1	S	Visits	StayVisits_Summer_N	0.641	0.489	0.764
1	S	SES	Employment_Inactive	0.398	0.304	0.764
1	M	Activities	WatchBotes_N	0.594	0.451	0.760
1	S	SES	2001-3000€/month	0.257	0.194	0.757
1	S	Health	Vitality_<Q1	0.243	0.181	0.748
1	S	Demography	VisitsKid_0-2	0.300	0.219	0.732
1	S	Demography	Household_1	0.333	0.241	0.722
1	S	Health	SF36MH_<Q1	0.252	0.181	0.720
1	S	Demography	>=65y	0.194	0.139	0.719
1	S	Visits	DaysAtCoast_2-3	0.411	0.295	0.719
1	S	Experiences	ProblemSolving_N	0.560	0.401	0.716
1	M	Activities	BeachSports_N	0.868	0.612	0.705
1	S	SES	<2000€/month	0.218	0.148	0.677
1	S	Experiences	SituateFeelingsThoughts_N	0.258	0.173	0.670
1	S	Experiences	GainingSelfConfidence_N	0.404	0.270	0.668
1	M	Activities	Cycling_N	0.647	0.430	0.665
1	M	Social company	WithParentsGrandparents_N	0.752	0.494	0.657
1	M	Social company	WithPartner_N	0.285	0.181	0.637
1	S	Experiences	EnjoyingExtent_N	0.175	0.110	0.626
1	M	Activities	ExploringCity_N	0.263	0.165	0.626
1	M	Activities	Pier_N	0.303	0.190	0.626
1	S	Experiences	EnjoyingSummerCrowding_N	0.634	0.397	0.625
1	M	Activities	RentGoCart_N	0.814	0.506	0.622
1	M	Activities	WatchSunset_N	0.438	0.270	0.617
1	M	Activities	WindowShopping_N	0.402	0.241	0.599
1	S	Experiences	ConnectingWithNature_N	0.165	0.097	0.588
1	S	Experiences	EnjoyingSandToes_N	0.442	0.241	0.544
1	M	Activities	WalkingInDunes_N	0.288	0.156	0.542
1	M	Activities	TakingPictures_N	0.195	0.105	0.541
1	M	Activities	WalkingAtBeach_N	0.125	0.068	0.539
1	S	Experiences	BeingFascinated_N	0.173	0.093	0.537
1	M	Activities	Picknick_N	0.560	0.295	0.528

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
1	S	Experiences	EnjoyingSoundOfWaves_N	0.101	0.051	0.499
1	M	Activities	VisitingFamily_N	0.753	0.376	0.499
1	S	Experiences	BeingInAwe_N	0.265	0.131	0.494
1	S	Experiences	LosingTrackOfTime_N	0.220	0.105	0.480
1	M	Activities	SearchingShells_N	0.565	0.270	0.478
1	M	Activities	DrinkAlcohol_N	0.375	0.177	0.473
1	S	Experiences	FeelingCompatible_N	0.207	0.093	0.449
1	S	Demography	Household_0	0.136	0.059	0.435
1	M	Social company	WithFriends_N	0.525	0.224	0.426
1	S	Experiences	FeelingPhysicalRest_N	0.129	0.055	0.425
1	M	Activities	SpendTimeOnBeach_N	0.472	0.198	0.421
1	M	Activities	VisitingFriend_N	0.635	0.266	0.419
1	M	Activities	BeachBar_N	0.488	0.194	0.397
1	S	Experiences	FeelingActive_N	0.216	0.084	0.391
1	S	Experiences	FeelingFree_N	0.101	0.034	0.335
1	S	Visits	DaysAtCoast_1	0.102	0.034	0.330
1	S	Experiences	FeelingAtHome_N	0.213	0.068	0.317
1	M	Activities	Seagoing_N	0.451	0.139	0.309
1	M	Activities	Restaurant_N	0.151	0.046	0.307
1	M	Activities	PlayWithKids_N	0.592	0.165	0.278
1	M	Activities	HaveAGoodTalk_N	0.109	0.030	0.271
1	M	Social company	WithFamily_N	0.562	0.152	0.270
1	M	Social company	WithKids_N	0.548	0.143	0.262
1	S	Experiences	HavingHolidayVibes_N	0.113	0.030	0.262
1	M	Activities	TerraceTearoomCafe_N	0.124	0.021	0.171
2	M	Social company	WithKids_Y	0.452	0.762	1.684
2	M	Activities	PlayWithKids_Y	0.408	0.672	1.648
2	M	Social company	WithFriends_N	0.525	0.772	1.469
2	M	Activities	SearchingShells_Y	0.435	0.623	1.432
2	M	Activities	VisitingFriend_N	0.635	0.854	1.345
2	S	Demography	40-49y	0.202	0.268	1.328
2	S	Demography	30-39y	0.171	0.222	1.295
2	S	Demography	Household_>1	0.531	0.662	1.248
2	M	Activities	Seagoing_Y	0.549	0.662	1.206
2	M	Social company	WithPartner_Y	0.715	0.861	1.204
2	M	Activities	ShowsFestivals_N	0.722	0.864	1.197
2	M	Activities	SpendTimeOnBeach_Y	0.528	0.632	1.197
2	S	SES	ISCED5-8	0.430	0.510	1.186
2	M	Social company	Alone_N	0.813	0.944	1.160
2	S	Experiences	EnjoyingSandToes_Y	0.558	0.632	1.134
2	M	Activities	VisitingFamily_N	0.753	0.844	1.122
2	M	Activities	Picknick_Y	0.440	0.493	1.121
2	M	Activities	TerraceTearoomCafe_Y	0.876	0.977	1.115
2	S	Demography	Household_Partner_N	0.627	0.699	1.113
2	M	Activities	TakingPictures_Y	0.805	0.891	1.107
2	M	Activities	BeachBar_N	0.488	0.540	1.105
2	M	Activities	WalkingAtBeach_Y	0.875	0.964	1.101
2	S	Visits	DayVisits_Fall_N	0.671	0.732	1.091
2	M	Activities	TakingTheDog_N	0.807	0.881	1.091
2	M	Activities	Restaurant_Y	0.849	0.924	1.089
2	M	Activities	StrollOnDike_Y	0.889	0.967	1.088
2	S	Visits	DayVisits_Winter_N	0.644	0.699	1.086
2	M	Social company	WithClub_N	0.908	0.977	1.076
2	M	Activities	HaveAGoodTalk_Y	0.891	0.950	1.067
2	S	Demography	CoastalHolidayResidence_N	0.899	0.950	1.057
2	M	Activities	Picknick_N	0.560	0.507	0.905
2	M	Activities	BeachBar_Y	0.512	0.460	0.900
2	S	SES	ISCED3-4	0.441	0.377	0.856
2	S	Visits	DayVisits_Winter_Y	0.356	0.301	0.846
2	S	Experiences	EnjoyingSandToes_N	0.442	0.368	0.831
2	S	Visits	DaysAtCoast_>8	0.272	0.222	0.816
2	S	Visits	DayVisits_Fall_Y	0.329	0.268	0.814
2	S	Demography	Household_Partner_Y	0.373	0.301	0.809
2	M	Activities	SpendTimeOnBeach_N	0.472	0.368	0.779

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
2	M	Activities	Seagoing_N	0.451	0.338	0.749
2	S	SES	<2000€/month	0.218	0.162	0.744
2	S	Demography	West Flanders	0.230	0.159	0.692
2	M	Activities	SearchingShells_N	0.565	0.377	0.668
2	M	Activities	VisitingFamily_Y	0.247	0.156	0.629
2	M	Activities	TakingTheDog_Y	0.193	0.119	0.618
2	S	Demography	18-29y	0.162	0.093	0.572
2	M	Activities	TakingPictures_N	0.195	0.109	0.560
2	M	Activities	PlayWithKids_N	0.592	0.328	0.554
2	M	Activities	Restaurant_N	0.151	0.076	0.503
2	S	Demography	CoastalHolidayResidence_Y	0.101	0.050	0.494
2	M	Activities	ShowsFestivals_Y	0.278	0.136	0.488
2	M	Social company	WithPartner_N	0.285	0.139	0.488
2	M	Social company	WithFriends_Y	0.475	0.228	0.481
2	M	Activities	HaveAGoodTalk_N	0.109	0.050	0.455
2	M	Social company	WithKids_N	0.548	0.238	0.435
2	M	Activities	VisitingFriend_Y	0.365	0.146	0.399
2	S	Demography	Household_0	0.136	0.053	0.390
2	M	Social company	Alone_Y	0.187	0.056	0.302
2	M	Activities	StrollOnDike_N	0.111	0.033	0.297
2	M	Activities	WalkingAtBeach_N	0.125	0.036	0.291
2	M	Social company	WithClub_Y	0.092	0.023	0.251
2	M	Activities	TerraceTearoomCafe_N	0.124	0.023	0.187
3	M	Social company	WithClub_Y	0.092	0.180	1.958
3	M	Social company	Alone_Y	0.187	0.327	1.752
3	M	Activities	ShowsFestivals_Y	0.278	0.481	1.731
3	M	Activities	WatchBotes_Y	0.406	0.643	1.582
3	S	Demography	Household_0	0.136	0.214	1.576
3	M	Activities	HistoryMonumentExhibitionMuseum_Y	0.448	0.692	1.545
3	M	Activities	WildlifeSpotting_Y	0.308	0.466	1.514
3	M	Social company	WithFriends_Y	0.475	0.711	1.497
3	M	Activities	VisitingFriend_Y	0.365	0.541	1.484
3	M	Activities	WatchSunset_Y	0.562	0.823	1.464
3	M	Social company	WithPartner_N	0.285	0.410	1.438
3	M	Social company	WithKids_N	0.548	0.782	1.428
3	M	Activities	BeachBar_Y	0.512	0.726	1.418
3	M	Activities	PlayWithKids_N	0.592	0.838	1.416
3	S	SES	<2000€/month	0.218	0.305	1.396
3	S	Demography	18-29y	0.162	0.222	1.369
3	M	Activities	Picknick_Y	0.440	0.579	1.316
3	S	Demography	>=65y	0.194	0.252	1.301
3	M	Activities	Cycling_Y	0.353	0.455	1.290
3	M	Activities	WindowShopping_Y	0.598	0.771	1.288
3	M	Activities	SpendTimeOnBeach_Y	0.528	0.677	1.281
3	S	Visits	StayVisits_Fall_Y	0.185	0.237	1.280
3	S	Visits	DaysAtCoast_>8	0.272	0.342	1.258
3	M	Activities	ExploringCity_Y	0.737	0.925	1.254
3	M	Activities	Seagoing_Y	0.549	0.680	1.239
3	M	Activities	Pier_Y	0.697	0.861	1.236
3	S	Experiences	ProblemSolving_Y	0.440	0.541	1.230
3	S	Health	PhysicalActivity_>Q3	0.267	0.327	1.227
3	M	Activities	WalkingInDunes_Y	0.712	0.872	1.225
3	S	Experiences	EnjoyingSandToes_Y	0.558	0.680	1.220
3	S	Visits	StayVisits_Spring_Y	0.263	0.320	1.213
3	S	Experiences	GainingSelfConfidence_Y	0.596	0.695	1.167
3	S	Experiences	BeingInAwe_Y	0.735	0.857	1.166
3	S	Experiences	RecallingMemories_Y	0.666	0.774	1.163
3	S	SES	Employment_Inactive	0.398	0.462	1.162
3	S	Experiences	EnjoyingSummerCrowding_Y	0.366	0.425	1.162
3	S	Demography	Female	0.518	0.598	1.153
3	M	Activities	DrinkAlcohol_Y	0.625	0.714	1.143
3	M	Activities	Restaurant_Y	0.849	0.966	1.138
3	S	Experiences	BeingFascinated_Y	0.827	0.936	1.132
3	M	Activities	TakingPictures_Y	0.805	0.910	1.130

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
3	M	Activities	WalkingAtBeach_Y	0.875	0.981	1.122
3	S	Visits	DayVisits_Summer_Y	0.550	0.617	1.121
3	S	Experiences	EnjoyingExtent_Y	0.825	0.921	1.117
3	M	Activities	TerraceTearoomCafe_Y	0.876	0.977	1.115
3	S	Experiences	FeelingCompatible_Y	0.793	0.883	1.114
3	S	Demography	Part-time	0.591	0.658	1.112
3	S	Experiences	LosingTrackOfTime_Y	0.780	0.865	1.108
3	S	Experiences	FeelingActive_Y	0.784	0.868	1.107
3	S	Experiences	SituateFeelingsThoughts_Y	0.742	0.820	1.105
3	S	Experiences	ConnectingWithNature_Y	0.835	0.917	1.099
3	S	Experiences	EnjoyingOffSeasonCalmness_Y	0.859	0.940	1.094
3	S	Experiences	EnjoyingSoundOfWaves_Y	0.899	0.981	1.092
3	S	Experiences	FeelingAtHome_Y	0.787	0.857	1.089
3	M	Activities	StrollOnDike_Y	0.889	0.966	1.087
3	M	Social company	WithParentsGrandparents_N	0.752	0.812	1.080
3	S	Experiences	FeelingPhysicalRest_Y	0.871	0.932	1.070
3	S	Experiences	FeelingHappier_Y	0.879	0.940	1.070
3	S	Experiences	HavingPeaceOfMind_Y	0.905	0.966	1.068
3	S	Experiences	FeelingFree_Y	0.899	0.959	1.066
3	S	Experiences	HavingHolidayVibes_Y	0.887	0.944	1.064
3	M	Activities	HaveAGoodTalk_Y	0.891	0.947	1.063
3	S	Visits	StayVisits_Fall_N	0.815	0.763	0.937
3	S	Visits	StayVisits_Spring_N	0.737	0.680	0.924
3	S	Experiences	EnjoyingSummerCrowding_N	0.634	0.575	0.907
3	M	Social company	WithClub_N	0.908	0.820	0.903
3	S	SES	Employment_Active	0.602	0.538	0.893
3	S	SES	ISCED5-8	0.430	0.372	0.865
3	S	Visits	DayVisits_Summer_N	0.450	0.383	0.852
3	M	Activities	Cycling_N	0.647	0.545	0.842
3	S	Demography	Household_>1	0.531	0.444	0.836
3	S	Demography	Male	0.476	0.395	0.829
3	M	Social company	Alone_N	0.813	0.673	0.827
3	M	Social company	WithPartner_Y	0.715	0.590	0.825
3	S	Experiences	ProblemSolving_N	0.560	0.459	0.819
3	M	Activities	WildlifeSpotting_N	0.692	0.534	0.771
3	M	Activities	DrinkAlcohol_N	0.375	0.286	0.762
3	M	Social company	WithParentsGrandparents_Y	0.248	0.188	0.758
3	S	Experiences	GainingSelfConfidence_N	0.404	0.305	0.754
3	M	Activities	Picknick_N	0.560	0.421	0.752
3	S	Experiences	EnjoyingSandToes_N	0.442	0.320	0.722
3	M	Activities	VisitingFriend_N	0.635	0.459	0.722
3	M	Activities	ShowsFestivals_N	0.722	0.519	0.719
3	M	Activities	Seagoing_N	0.451	0.320	0.709
3	S	Experiences	SituateFeelingsThoughts_N	0.258	0.180	0.699
3	M	Activities	SpendTimeOnBeach_N	0.472	0.323	0.686
3	S	Experiences	RecallingMemories_N	0.334	0.226	0.675
3	S	Experiences	FeelingAtHome_N	0.213	0.143	0.671
3	S	Demography	30-39y	0.171	0.109	0.637
3	S	Experiences	LosingTrackOfTime_N	0.220	0.135	0.616
3	S	Experiences	FeelingActive_N	0.216	0.132	0.610
3	M	Activities	WatchBotes_N	0.594	0.357	0.602
3	M	Activities	WindowShopping_N	0.402	0.229	0.571
3	S	Experiences	FeelingCompatible_N	0.207	0.117	0.564
3	M	Activities	BeachBar_N	0.488	0.274	0.562
3	M	Activities	HistoryMonumentExhibitionMuseum_N	0.552	0.308	0.558
3	M	Social company	WithFriends_N	0.525	0.289	0.551
3	S	Experiences	BeingInAwe_N	0.265	0.143	0.539
3	S	Experiences	FeelingPhysicalRest_N	0.129	0.068	0.524
3	S	Experiences	ConnectingWithNature_N	0.165	0.083	0.501
3	S	Experiences	HavingHolidayVibes_N	0.113	0.056	0.499
3	S	Experiences	FeelingHappier_N	0.121	0.060	0.496
3	S	Demography	40-49y	0.202	0.098	0.484
3	M	Activities	HaveAGoodTalk_N	0.109	0.053	0.483
3	M	Social company	WithKids_Y	0.452	0.218	0.482

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
3	M	Activities	TakingPictures_N	0.195	0.090	0.462
3	M	Activities	Pier_N	0.303	0.139	0.458
3	S	Experiences	EnjoyingExtent_N	0.175	0.079	0.451
3	M	Activities	WalkingInDunes_N	0.288	0.128	0.444
3	S	Experiences	EnjoyingOffSeasonCalmness_N	0.141	0.060	0.428
3	S	Experiences	FeelingFree_N	0.101	0.041	0.411
3	M	Activities	WatchSunset_N	0.438	0.177	0.404
3	M	Activities	PlayWithKids_Y	0.408	0.162	0.396
3	S	Experiences	BeingFascinated_N	0.173	0.064	0.370
3	S	Visits	DaysAtCoast_1	0.102	0.038	0.368
3	S	Experiences	HavingPeaceOfMind_N	0.095	0.034	0.355
3	M	Activities	StrollOnDike_N	0.111	0.034	0.304
3	M	Activities	ExploringCity_N	0.263	0.075	0.286
3	M	Activities	Restaurant_N	0.151	0.034	0.224
3	S	Experiences	EnjoyingSoundOfWaves_N	0.101	0.019	0.185
3	M	Activities	TerraceTearoomCafe_N	0.124	0.023	0.182
3	M	Activities	WalkingAtBeach_N	0.125	0.019	0.150
4	M	Activities	WalkingAtBeach_N	0.125	0.287	2.295
4	M	Activities	Seagoing_N	0.451	0.873	1.937
4	M	Activities	SpendTimeOnBeach_N	0.472	0.836	1.772
4	M	Social company	WithKids_N	0.548	0.903	1.649
4	M	Activities	WalkingInDunes_N	0.288	0.463	1.606
4	M	Activities	SearchingShells_N	0.565	0.907	1.604
4	S	Demography	Household_1	0.333	0.526	1.578
4	S	Experiences	EnjoyingSandToes_N	0.442	0.698	1.577
4	M	Activities	TakingPictures_N	0.195	0.306	1.568
4	S	Demography	Household_Partner_Y	0.373	0.582	1.563
4	M	Activities	PlayWithKids_N	0.592	0.918	1.550
4	M	Activities	WatchSunset_N	0.438	0.675	1.543
4	S	Experiences	EnjoyingSoundOfWaves_N	0.101	0.153	1.509
4	M	Activities	Picknick_N	0.560	0.821	1.466
4	S	Experiences	FeelingCompatible_N	0.207	0.295	1.427
4	S	Experiences	ConnectingWithNature_N	0.165	0.231	1.401
4	S	Experiences	BeingFascinated_N	0.173	0.235	1.360
4	M	Social company	WithFamily_N	0.562	0.761	1.354
4	S	Experiences	FeelingActive_N	0.216	0.287	1.331
4	S	Demography	>=65y	0.194	0.257	1.330
4	S	Experiences	RecallingMemories_N	0.334	0.440	1.318
4	S	Experiences	BeingInAwe_N	0.265	0.343	1.296
4	S	SES	Employment_Inactive	0.398	0.496	1.247
4	M	Activities	BeachBar_N	0.488	0.608	1.245
4	S	Health	PhysicalActivity_<Q1	0.230	0.280	1.219
4	M	Social company	WithParentsGrandparents_N	0.752	0.899	1.196
4	M	Activities	Pier_N	0.303	0.362	1.193
4	M	Activities	Cycling_N	0.647	0.772	1.193
4	M	Activities	WildlifeSpotting_N	0.692	0.825	1.192
4	M	Activities	RentGoCart_N	0.814	0.966	1.187
4	M	Activities	VisitingFamily_N	0.753	0.873	1.160
4	S	Experiences	ProblemSolving_N	0.560	0.649	1.160
4	M	Social company	WithFriends_N	0.525	0.608	1.158
4	M	Activities	VisitingFriend_N	0.635	0.735	1.157
4	S	Experiences	GainingSelfConfidence_N	0.404	0.466	1.155
4	S	Visits	StayVisits_Summer_N	0.641	0.739	1.153
4	M	Activities	BeachSports_N	0.868	1.000	1.152
4	M	Activities	Restaurant_Y	0.849	0.970	1.143
4	S	SES	ISCED3-4	0.441	0.504	1.143
4	M	Activities	Watersports_N	0.878	0.996	1.135
4	M	Activities	DrinkAlcohol_Y	0.625	0.709	1.134
4	M	Activities	TerraceTearoomCafe_Y	0.876	0.974	1.111
4	M	Activities	HistoryMonumentExhibitionMuseum_N	0.552	0.612	1.108
4	S	Experiences	EnjoyingSummerCrowding_N	0.634	0.701	1.106
4	M	Activities	WatchBotes_N	0.594	0.653	1.100
4	M	Activities	RentALounge_N	0.917	1.000	1.090
4	M	Social company	Alone_N	0.813	0.884	1.087

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
4	M	Activities	Jogging_N	0.896	0.970	1.082
4	S	Visits	StayVisits_Spring_N	0.737	0.791	1.074
4	M	Activities	ExploringCity_Y	0.737	0.791	1.073
4	M	Activities	ShowsFestivals_N	0.722	0.772	1.070
4	M	Social company	WithClub_N	0.908	0.966	1.065
4	S	Experiences	EnjoyingSoundOfWaves_Y	0.899	0.847	0.943
4	S	Experiences	BeingFascinated_Y	0.827	0.765	0.925
4	S	Experiences	ConnectingWithNature_Y	0.835	0.769	0.921
4	M	Activities	Pier_Y	0.697	0.638	0.916
4	S	Experiences	FeelingActive_Y	0.784	0.713	0.909
4	S	Experiences	GainingSelfConfidence_Y	0.596	0.534	0.895
4	S	Experiences	BeingInAwe_Y	0.735	0.657	0.893
4	S	Experiences	FeelingCompatible_Y	0.793	0.705	0.889
4	M	Activities	HistoryMonumentExhibitionMuseum_Y	0.448	0.388	0.867
4	M	Activities	TakingPictures_Y	0.805	0.694	0.862
4	M	Activities	WatchBotes_Y	0.406	0.347	0.854
4	S	Experiences	RecallingMemories_Y	0.666	0.560	0.841
4	S	SES	Employment_Active	0.602	0.504	0.837
4	M	Social company	WithFriends_Y	0.475	0.392	0.825
4	M	Activities	ShowsFestivals_Y	0.278	0.228	0.819
4	S	Experiences	EnjoyingSummerCrowding_Y	0.366	0.299	0.817
4	M	Activities	WalkingAtBeach_Y	0.875	0.713	0.815
4	S	Experiences	ProblemSolving_Y	0.440	0.351	0.797
4	M	Activities	ExploringCity_N	0.263	0.209	0.795
4	S	Visits	StayVisits_Spring_Y	0.263	0.209	0.793
4	S	SES	ISCED5-8	0.430	0.340	0.789
4	M	Activities	DrinkAlcohol_N	0.375	0.291	0.777
4	M	Activities	BeachBar_Y	0.512	0.392	0.766
4	M	Activities	WalkingInDunes_Y	0.712	0.537	0.755
4	S	Health	PhysicalActivity_>Q3	0.267	0.194	0.728
4	S	Visits	StayVisits_Summer_Y	0.359	0.261	0.727
4	M	Activities	VisitingFriend_Y	0.365	0.265	0.726
4	S	Demography	40-49y	0.202	0.142	0.702
4	S	Demography	Household_Partner_N	0.627	0.418	0.666
4	M	Activities	Cycling_Y	0.353	0.228	0.646
4	M	Social company	Alone_Y	0.187	0.116	0.620
4	S	Demography	Household_>1	0.531	0.321	0.605
4	M	Activities	WatchSunset_Y	0.562	0.325	0.577
4	M	Activities	WildlifeSpotting_Y	0.308	0.175	0.569
4	M	Social company	WithFamily_Y	0.438	0.239	0.545
4	S	Experiences	EnjoyingSandToes_Y	0.558	0.302	0.542
4	M	Activities	VisitingFamily_Y	0.247	0.127	0.513
4	M	Activities	Picknick_Y	0.440	0.179	0.407
4	M	Social company	WithParentsGrandparents_Y	0.248	0.101	0.406
4	M	Social company	WithClub_Y	0.092	0.034	0.364
4	M	Activities	SpendTimeOnBeach_Y	0.528	0.164	0.311
4	M	Activities	Jogging_Y	0.104	0.030	0.288
4	M	Activities	Seagoing_Y	0.549	0.127	0.231
4	M	Activities	SearchingShells_Y	0.435	0.093	0.215
4	M	Social company	WithKids_Y	0.452	0.097	0.214
4	M	Activities	TerraceTearoomCafe_N	0.124	0.026	0.211
4	M	Activities	PlayWithKids_Y	0.408	0.082	0.201
4	M	Activities	Restaurant_N	0.151	0.030	0.197
4	M	Activities	RentGoCart_Y	0.186	0.034	0.181
4	M	Activities	Watersports_Y	0.122	0.004	0.031
4	M	Activities	BeachSports_Y	0.132	0.000	0.000
4	M	Activities	RentALounge_Y	0.083	0.000	0.000
5	M	Activities	TerraceTearoomCafe_N	0.124	0.594	4.803
5	M	Activities	Restaurant_N	0.151	0.638	4.214
5	M	Activities	StrollOnDike_N	0.111	0.397	3.568
5	M	Activities	HaveAGoodTalk_N	0.109	0.371	3.403
5	S	Experiences	EnjoyingTheView_N	0.048	0.148	3.118
5	S	Experiences	EnjoyingSeaAir_N	0.040	0.114	2.843
5	M	Activities	ExploringCity_N	0.263	0.707	2.693

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
5	S	Experiences	BeingRelaxed_N	0.033	0.083	2.512
5	S	Experiences	HavingHolidayVibes_N	0.113	0.275	2.437
5	S	Experiences	FeelingFree_N	0.101	0.223	2.213
5	S	Visits	DaysAtCoast_1	0.102	0.223	2.180
5	S	Experiences	EnjoyingSoundOfWaves_N	0.101	0.218	2.154
5	S	Experiences	FeelingHappier_N	0.121	0.249	2.051
5	S	Experiences	BeingAway_N	0.096	0.197	2.047
5	S	Demography	5-20km	0.062	0.127	2.036
5	M	Activities	TakingPictures_N	0.195	0.393	2.015
5	S	Experiences	FeelingPhysicalRest_N	0.129	0.258	1.997
5	M	Activities	DrinkAlcohol_N	0.375	0.747	1.992
5	S	Experiences	FeelingAtHome_N	0.213	0.424	1.991
5	S	Experiences	HavingPeaceOfMind_N	0.095	0.188	1.972
5	M	Activities	Pier_N	0.303	0.590	1.943
5	M	Activities	WindowShopping_N	0.402	0.769	1.913
5	S	Experiences	BeingFascinated_N	0.173	0.328	1.895
5	M	Activities	WalkingAtBeach_N	0.125	0.236	1.884
5	S	Experiences	LosingTrackOfTime_N	0.220	0.406	1.849
5	S	Experiences	FeelingCompatible_N	0.207	0.371	1.797
5	S	Experiences	EnjoyingExtent_N	0.175	0.310	1.771
5	S	Experiences	BeingInAwe_N	0.265	0.459	1.730
5	M	Activities	BeachBar_N	0.488	0.834	1.707
5	M	Social company	WithPartner_N	0.285	0.467	1.640
5	S	Experiences	FeelingActive_N	0.216	0.349	1.619
5	S	Demography	West Flanders	0.230	0.367	1.597
5	M	Activities	WalkingInDunes_N	0.288	0.459	1.592
5	M	Social company	Alone_Y	0.187	0.297	1.591
5	S	Experiences	EnjoyingOffSeasonCalmness_N	0.141	0.223	1.585
5	S	Demography	SocialSupport_0-1	0.108	0.170	1.584
5	S	Demography	Household_0	0.136	0.214	1.574
5	M	Activities	HistoryMonumentExhibitionMuseum_N	0.552	0.860	1.558
5	S	Experiences	ConnectingWithNature_N	0.165	0.253	1.534
5	M	Activities	WatchSunset_N	0.438	0.664	1.516
5	S	Health	Vitality_<Q1	0.243	0.367	1.511
5	M	Activities	WatchBotes_N	0.594	0.882	1.486
5	S	Demography	20-50km	0.126	0.179	1.421
5	S	Experiences	SituateFeelingsThoughts_N	0.258	0.367	1.421
5	S	Demography	18-29y	0.162	0.227	1.401
5	S	Experiences	GainingSelfConfidence_N	0.404	0.559	1.384
5	M	Activities	Picknick_N	0.560	0.760	1.357
5	M	Activities	SpendTimeOnBeach_N	0.472	0.638	1.352
5	S	Experiences	EnjoyingSandToes_N	0.442	0.594	1.342
5	S	Experiences	EnjoyingSummerCrowding_N	0.634	0.852	1.342
5	S	Health	SF36MH_<Q1	0.252	0.332	1.317
5	M	Social company	WithFriends_N	0.525	0.690	1.313
5	M	Social company	WithFamily_N	0.562	0.729	1.297
5	M	Activities	Seagoing_N	0.451	0.581	1.288
5	S	Health	Emotional_<Q1	0.237	0.306	1.288
5	M	Activities	VisitingFriend_N	0.635	0.817	1.286
5	S	SES	<2000€/month	0.218	0.279	1.281
5	S	Experiences	RecallingMemories_N	0.334	0.428	1.281
5	M	Social company	WithKids_N	0.548	0.686	1.252
5	M	Activities	ShowsFestivals_N	0.722	0.886	1.228
5	S	Visits	StayVisits_Summer_N	0.641	0.786	1.227
5	S	Experiences	ProblemSolving_N	0.560	0.686	1.224
5	M	Activities	SearchingShells_N	0.565	0.690	1.221
5	M	Activities	PlayWithKids_N	0.592	0.716	1.209
5	M	Activities	Cycling_N	0.647	0.782	1.207
5	M	Activities	RentGoCart_N	0.814	0.965	1.185
5	S	Demography	Household_Partner_N	0.627	0.738	1.176
5	S	Visits	StayVisits_Spring_N	0.737	0.860	1.168
5	M	Activities	VisitingFamily_N	0.753	0.873	1.160
5	S	Visits	StayVisits_Winter_N	0.797	0.917	1.150
5	M	Activities	WildlifeSpotting_N	0.692	0.790	1.142

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
5	S	Demography	Part-time	0.591	0.655	1.108
5	S	Visits	StayVisits_Fall_N	0.815	0.895	1.099
5	M	Activities	RentALounge_N	0.917	0.974	1.062
5	M	Activities	BeachSports_N	0.868	0.921	1.062
5	S	Experiences	EnjoyingSeaAir_Y	0.960	0.886	0.923
5	S	Experiences	EnjoyingOffSeasonCalmness_Y	0.859	0.777	0.904
5	S	Experiences	HavingPeaceOfMind_Y	0.905	0.812	0.898
5	S	Experiences	ConnectingWithNature_Y	0.835	0.747	0.894
5	S	Experiences	EnjoyingTheView_Y	0.952	0.852	0.894
5	S	Experiences	BeingAway_Y	0.904	0.803	0.889
5	M	Activities	WalkingAtBeach_Y	0.875	0.764	0.874
5	S	Experiences	EnjoyingSoundOfWaves_Y	0.899	0.782	0.870
5	M	Social company	Alone_N	0.813	0.703	0.864
5	S	Experiences	FeelingFree_Y	0.899	0.777	0.864
5	S	Experiences	RecallingMemories_Y	0.666	0.572	0.859
5	S	Experiences	FeelingHappier_Y	0.879	0.751	0.855
5	S	Experiences	SituateFeelingsThoughts_Y	0.742	0.633	0.853
5	S	Experiences	FeelingPhysicalRest_Y	0.871	0.742	0.852
5	S	Experiences	EnjoyingExtent_Y	0.825	0.690	0.836
5	S	Experiences	FeelingActive_Y	0.784	0.651	0.830
5	S	Experiences	HavingHolidayVibes_Y	0.887	0.725	0.817
5	S	Experiences	BeingFascinated_Y	0.827	0.672	0.813
5	S	Health	Emotional_Q2-Q3	0.284	0.227	0.799
5	S	Experiences	FeelingCompatible_Y	0.793	0.629	0.793
5	S	Demography	>100km	0.452	0.354	0.782
5	S	Demography	Household_1	0.333	0.258	0.773
5	M	Activities	Seagoing_Y	0.549	0.419	0.763
5	S	Experiences	LosingTrackOfTime_Y	0.780	0.594	0.761
5	M	Activities	WalkingInDunes_Y	0.712	0.541	0.761
5	M	Activities	TakingPictures_Y	0.805	0.607	0.754
5	S	SES	3001-4000€/month	0.251	0.188	0.748
5	M	Social company	WithPartner_Y	0.715	0.533	0.745
5	S	Experiences	GainingSelfConfidence_Y	0.596	0.441	0.740
5	S	Experiences	BeingInAwe_Y	0.735	0.541	0.737
5	S	Experiences	FeelingAtHome_Y	0.787	0.576	0.732
5	S	Experiences	EnjoyingSandToes_Y	0.558	0.406	0.728
5	S	Experiences	ProblemSolving_Y	0.440	0.314	0.714
5	M	Activities	SearchingShells_Y	0.435	0.310	0.713
5	M	Activities	HaveAGoodTalk_Y	0.891	0.629	0.706
5	S	Demography	Household_Partner_Y	0.373	0.262	0.703
5	M	Activities	PlayWithKids_Y	0.408	0.284	0.696
5	M	Social company	WithKids_Y	0.452	0.314	0.695
5	M	Activities	SpendTimeOnBeach_Y	0.528	0.362	0.686
5	M	Activities	WildlifeSpotting_Y	0.308	0.210	0.681
5	M	Activities	StrollOnDike_Y	0.889	0.603	0.678
5	M	Social company	WithFriends_Y	0.475	0.310	0.653
5	M	Activities	Cycling_Y	0.353	0.218	0.619
5	M	Social company	WithFamily_Y	0.438	0.271	0.618
5	M	Activities	WatchSunset_Y	0.562	0.336	0.598
5	S	Visits	StayVisits_Summer_Y	0.359	0.214	0.595
5	M	Activities	BeachSports_Y	0.132	0.079	0.595
5	S	Visits	DaysAtCoast_>8	0.272	0.162	0.594
5	M	Activities	Pier_Y	0.697	0.410	0.589
5	S	Visits	StayVisits_Fall_Y	0.185	0.105	0.566
5	M	Activities	Picknick_Y	0.440	0.240	0.546
5	S	Visits	StayVisits_Spring_Y	0.263	0.140	0.530
5	M	Activities	VisitingFamily_Y	0.247	0.127	0.512
5	M	Activities	VisitingFriend_Y	0.365	0.183	0.503
5	M	Activities	TerraceTearoomCafe_Y	0.876	0.406	0.463
5	M	Activities	Restaurant_Y	0.849	0.362	0.427
5	S	Visits	StayVisits_Winter_Y	0.203	0.083	0.409
5	M	Activities	ShowsFestivals_Y	0.278	0.114	0.408
5	S	Experiences	EnjoyingSummerCrowding_Y	0.366	0.148	0.406
5	M	Activities	DrinkAlcohol_Y	0.625	0.253	0.405

Cluster	M/S	Type	Category	Sample (%)	Cluster (%)	Cluster/Sample
5	M	Activities	ExploringCity_Y	0.737	0.293	0.397
5	M	Activities	WindowShopping_Y	0.598	0.231	0.387
5	M	Activities	BeachBar_Y	0.512	0.166	0.324
5	M	Activities	RentALounge_Y	0.083	0.026	0.316
5	M	Activities	HistoryMonumentExhibitionMuseum_Y	0.448	0.140	0.312
5	M	Activities	WatchBotes_Y	0.406	0.118	0.290
5	M	Activities	RentGoCart_Y	0.186	0.035	0.188

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