Exploring the health context: A multimethod approach to climate change adaptation evaluation

Dissertation

to obtain the academic degree of
Dr. Public Health (Dr.PH)

submitted by
Melanie Böckmann

University of Bremen
Faculty of Human and Health Sciences

April 2015

Defended on: 29 June 2015

1st Reviewer: Prof. Dr. Hajo Zeeb, University of Bremen and Leibniz Institute for Prevention Research and Epidemiology – BIPS

2nd Reviewer: Prof. T. Andrew Joyner, PhD, East Tennessee State University

This dissertation is published in a shortened version.

Diese Dissertation ist in gekürzter Fassung veröffentlicht.

Folgende Änderungen liegen vor:

Manuskript Artikel 4: Publikation des Titels und Abstracts. Kein Volltext.

Manuskript Artikel 5: Publikation des Titels und Abstracts. Kein Volltext.

Appendix: Keine Veröffentlichung der Interview-Audioaufnahmen und Transkripte aus Datenschutzgründen. Veröffentlichung der Code-Liste im Anhang.

Abstract

Climate change is a major environmental Public Health issue of the 21st century. Extreme heat and cold, weather events such as flooding or storms, disease vector distribution changes, and increased pathogen loads in water might all put human health at risk. To protect health from inevitable changes, climate change adaptation strategies are implemented at local, national, and global level. Are these measures effectively reducing health risks? This dissertation explores multiple methods to evaluate climate change adaptation to increase our understanding of the contextual requirements for measurement of effects.

Health-related climate change adaptation is situated within theories of place and place-based vulnerability. Targeting two core research questions on effectiveness of adaptation and on useful approaches to evaluation, this mixed methods work combines a systematic review, policy analysis, risk factor modeling, situational analysis, and theoretical framework development on cases from Europe and Japan. The systematic review on effectiveness of heat adaptation showed challenges concerning attributing health outcomes directly to specific adaptation measures via epidemiological methods. Without conclusive evidence for individual adaptation items, emphasis instead is placed on policy evaluation, on risk factor distribution changes, and on local or "on the ground" adaptation. The data suggest that reframing effectiveness towards inequality and vulnerability reduction is a promising strategy for evaluation while dealing with gaps in the causal chains between adaptation and health outcomes.

Based on these findings, I argue that adaptation evaluation in Public Health could apply a portfolio of methods and theory-based solutions informed by structural prevention measures, qualitative methods such as context mapping, and transformation as a philosophy of change. Most importantly, a conceptual re-thinking of adaptation evaluation is suggested that positions social justice and place-based vulnerability concepts as imperatives for successful adaptation.

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Abbreviations

BASE	*Bottom-Up Climate Adaptation Strategies for a Sustainable Europe*
CASP	*Critical Appraisal Skills Program*
CDC	*Centers for Disease Control and Prevention*
CGIAR	*Fixed acronym, previously Consultative Group on International Agricultural Research*
CIRCLE	*Climate Impact Research & Response Coordination for a larger Europe*
CLIMATE-ADAPT	*European Climate Adaptation Platform*
CSIRO	*Commonwealth Scientific and Industrial Research Organization*
DALY	*Disability-adjusted Life Year*
EBPH	*Evidence-based Public Health*
EC	*European Commission*
ECCA	*European Climate Change Adaptation Conference*
ECDC	*European Centre for Disease Prevention and Control*
EPA	*Environmental Protection Agency*
EU	*European Union*
EuroHEAT	*Project on "Improving Public Health Responses to Extreme Weather/Heat Waves"*
GARP	*Genetic Algorithm for Rule Set Production*
GHG	*Greenhouse Gas*
HiAP	*Health in All Policies*
IPCC	*Intergovernmental Panel on Climate Change*
ISOTHURM	*International Study of Temperature, Heat and Urban Mortality*
OECD	*Organization for Economic Co-operation and Development*
PHEWE	*Project on "Assessment and Prevention of Acute Health Effects of Weather Conditions in Europe"*
PRISMA	*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*
PROVIA	*Global Program of Research on Climate Change Vulnerability, Impacts and Adaptation*

RAMSES	*Reconciling Adaptation, Mitigation and Sustainable Development for Cities*
RCP	*Representative Concentration Pathways*
RCT	*Randomized Controlled Trial*
SSP	*Shared Socio-economic Pathways*
SES	*Socio-economic Status*
SRES	*Special Report on Emissions Scenarios*
ToPDaD	*Tool-supported Policy Development for Regional Adaptation*
UHI	*Urban Heat Island*
UN	*United Nations*
UNEP	*United Nations Environment Program*
UNFCCC	*United Nations Framework Convention on Climate Change*
UN-HABITAT	*United Nations Human Settlements Program*
WHO	*World Health Organization*
WMO	*World Meteorological Organization*

Articles in this dissertation

Five articles comprise this cumulative dissertation and are referred to in the main text. All five are published or are undergoing an international peer-review process. Full article manuscripts can be found in the appendix for the published articles.

I Boeckmann, M., & Rohn, I. (2014). Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC Public Health*, *14*(1), 1112. doi:10.1186/1471-2458-14-1112

II Boeckmann, M., & Joyner, T. A. (2014). Old health risks in new places? An ecological niche model for I. ricinus tick distribution in Europe under a changing climate. *Health & Place*, *30C*, 70–77. doi:10.1016/j.healthplace.2014.08.004

III Boeckmann, M., & Zeeb, H. (2014). Using a social justice and health Framework to assess European climate change adaptation strategies. *International Journal of Environmental Research and Public Health*, *11*(12), 12389–12411. doi:10.3390/ijerph111212389

IV Boeckmann, M. (2015a). Exploring the health context: a qualitative study of local heat and climate change adaptation in Japan. *Submitted.*

V Boeckmann, M. (2015b). Reframing effectiveness: climate change adaptation, human health, and the role of climate justice in evaluation. *Submitted.*

An additional sixth manuscript derived from this research project. This is referred to in the thesis under section 5.1.1.

VI Boeckmann, M., Ng, CFS., Ueda K., Zeeb, H., Nitta, H., Watanabe, C., & Honda, Y. (2015). Heat-related mortality: effect modification and adaptation in Japan from 1972-2010. *Submitted.*

Acknowledgments

Everything makes everything else happen ~ Li-Young Lee

First, I would like to thank my primary advisor Prof. Hajo Zeeb for supporting my vision throughout the dissertation work. He facilitated my trip to Japan and has made me a better researcher and teacher. Prof. T. Andrew Joyner as second examiner accompanied the final stages with sage advice and an always open door for my concerns.

Many thanks to my additional co-authors, Ines Rohn, Dr. Kayo Ueda, and Dr. Chris Fook Sheng Ng, for their professionalism and persistence.

For support during my fieldwork in Japan, I owe deepest thanks to Dr. Hiroshi Nitta, Dr. Kayo Ueda, Dr. Chris Shook Feng Ng and the department of Environmental Health Sciences, to Dr. Kiyoshi Takahashi, Dr. Toshi Ichinose, Dr. Hancheng Dai and Yosuke Shigetomi at NIES, to Prof. Yasushi Honda for providing prefectural mortality data, to Prof. Nobuo Shirai for inviting me to the local adaptation forum, and to Dr. Masumoto for helping to arrange an interview. Chisato Chris Imai and Nagisa Mori shared their knowledge on research in Japan. Dr. Jostacio Lapitan and Gerardo Sanchez Martinez introduced me to the field of climate change and health.
I am indebted to my interviewees who freely gave their time and knowledge during the expert interviews.
My interpreters in Japan, John McDonald, Ryohei Yokoyama, and Yuta Negishi, helped me conduct the interviews. Aya Goto transcribed in Japanese, the transcripts were translated into German by Yuki Kobayashi.

I particularly want to thank Jasmina Crčić for the many hours we spent at coffee shops discussing our works and lives. Our meetings were necessary respites from the daily grind, and I look forward to future collaborations. Andres Osorio and Gengen He sent encouragement across oceans when it was needed the most.

Andrew McIntyre has been a gracious, patient, and consistent proofreader of article and thesis drafts, continuously letting me profit from his writerly expertise. At the Leibniz Institute for Prevention Research and Epidemiology - BIPS, Dr. Florence Samkange-Zeeb, Natascha Makarova, Berit Steenbock, Saskia Pöttgen, Steffen Dreger, Katharina Gallois, Dr. Katja Landgraf-Rauf, and Edda Hein have critiqued various article manuscript drafts. Many thanks to Amanda Whittal for proofreading the completed thesis manuscript. All remaining errors in this manuscript are my own.

I am grateful for the assistance I received throughout this process from my family, from Nadine Ochmann, Rebecca Mundhenk, my colleagues at the Leibniz Institute for Prevention Research and Epidemiology – BIPS, Dr. Libertad Chavez Rodriguez, Dr. Jenna Voss, Jann Reinhardt, and my colleagues at *Somatosphere*.

Finally, I want to thank Michael Lehmann for his unwavering support, whether I was spending long days abroad or in front of the computer screen. He made the dissertation and my life in the process much, much better.

I dedicate this work to Waheed, Parisa, and Hamid Tajik: may you become anything you hope to be.

This dissertation and its individual projects have been supported by the University of Bremen, the Leibniz Institute for Prevention Research and Epidemiology -BIPS, the German Academic Exchange Service (DAAD), Japan Society for the Promotion of the Sciences (JSPS), and the German Research Foundation (DFG).

1 Introduction

Climate change is a global issue currently at the forefront of public awareness. The potential health risks from climate change include increased storms and floods, extreme temperature events, changes in disease vector and pollen distribution, rising sea levels, and droughts (Smith et al. 2014). As climate-related morbidity and mortality is generally preventable, there is a need for the Public Health community to develop protective measures against these health risks. These protective measures are subsumed under the concept of climate change adaptation, strategies or projects to deal with inevitable climatic changes (European Evironment Agency (EEA) 2013).

Climate change adaptation is a relatively novel endeavor within a Public Health dilemma: adaptation aims at protecting human health from future potential risks, before the specific paths and causal relationships between climate change, adaptation and health are completely understood. As a systemic, imperfectly understood challenge without simple solutions, climate change adaptation has been termed a “wicked problem” (Feliciano & Berkhout 2013). While still analyzing this new global problem, the research and policymaking communities are already called upon to present solutions. This has led to a difficult relationship between politics and science: the latter takes time to learn, to solve, to prove, and to consider alternatives. The former is asked to make decisions after a relatively short deliberation process, and these decisions on how to mitigate and adapt to climate change may or may not impact human health in the future. At the same time, climate change experts and health experts are expected to contribute to these decision-making processes. In politics, delaying decisions when faced with complex problems is an option. In these situations, scientists may be expected to call for actions themselves. An ethical weighting process begins: current state of the art knowledge asserts that without timely implementation of mitigation and adaptation, humans in the near future will be confronted with climate change of previously unknown proportion (Schellnhuber et al. 2013), the risks of which cannot be satisfactorily estimated. At the same time, no conclusive evidence for the effectiveness

of health-related climate change adaptation exists (Bouzid et al. 2013), nor have comprehensive assessments of possible harms and benefits of adaptation strategies been conducted. In the interest of precaution, the limited evidence available already suggests that further examination of climate change, adaptation, and health issues is necessary. Finding solutions to the questions of whether adaptation can be effective and how to measure this effectiveness will likely become a central issue in environmental Public Health. This dissertation is situated within this topic.

Precisely because the associations of adaptation effects and health outcomes are not yet entirely understood, the task of this dissertation is to contribute to an explicit conceptualization of the evaluation problem in Public Health and climate adaptation. The theoretical debate on adaptation has focused mostly on disaster risks, development policy, and livelihoods (Krausing et al. 2013; Lamhauge et al. 2013; Hochrainer-Stigler et al. 2014; Solecki et al. 2011), yet a similar level of theorizing and scrutiny has been applied less often to the health and adaptation nexus until now. Thus, this dissertation contributes to the debate by investigating and conceptualizing possible approaches to the evaluation of climate change adaptation.

1.1 Scope and nature of my research

This research project focuses on climate change adaptation as planned policy initiatives, not on biological acclimatization. Owing to their high relevance in higher income countries (Smith et al. 2014; McMichael et al. 2012; Frumkin, McMichael, et al. 2008; Patz et al. 2014), heat and infectious diseases were specifically targeted in three studies within this project. Europe and Japan were chosen as field sites for their capacity to implement adaptation projects and their vulnerability to extreme temperature events (see the methods section for further details on study region selection). This work approaches adaptation from a Public Health perspective, but also draws from interdisciplinary influences such as human geography or anthropology. The research

was conducted over the course of three years, with a 2 month research visit to Japan, and is characterized by a constructivist position to data analysis.

1.2 Research questions and contribution

This work critically explores evaluation options for adaptation to health impacts of climate change through a multimethod approach. The research is driven by two core research questions:

a) How effective is climate change adaptation in protecting human health from negative consequences of climatic changes, with a specific focus on heat?
b) How could interdisciplinary science approach adaptation evaluation in Public Health?

These core questions can be broken down into three more detailed sub-questions, each studied within different approaches in this dissertation:

1. Is climate change adaptation effectively protecting human health?
   ➔ targeted in the systematic review, the policy analysis, the vector study
2. How could we measure adaptation effectiveness?
   ➔ targeted in the expert interviews, through risk factor change assessment in the vector study, through policy assessment with a social justice approach
3. And: what could an alternative framework, a reframing of effectiveness in adaptation and health research look like?
   ➔ targeted in the policy analysis and in the theoretical framework article

Overall, with this study I contribute to a re-thinking of the concepts of effectiveness and evaluation in climate change adaptation. Previous research has shown that the standard theories of how to define effectiveness do not always apply to climate change adaptation (Toloo et al. 2013; Bassil & Cole 2010; Boeckmann & Rohn 2014), as discussed in more detail in chapters three through five, and in the articles within this

thesis. As part of this work, I have developed a theoretical framework that targets the broader social, cultural and environmental determinants of health for evaluation. Such a novel proposition of what effectiveness could entail, namely effects on inequity reduction, could contribute to a better awareness of the importance of context and connectedness within climate adaptation and the health nexus. The framework might additionally alleviate the challenges of attributing adaptation to health outcomes directly. Of major interest is the opportunity to promote social and climate justice through adaptation, by strengthening their roles as evaluation criteria, as demonstrated in this thesis' policy analysis as well as in the evaluation framework.

1.3 Principal findings

This study engages with the question of the effectiveness of climate change adaptation and comes to the conclusion that standard epidemiological methods are not yet fully equipped to give the answers needed. Two overarching solution paths are possible: refining evaluation methods, and expanding the conceptual scope of adaptation. Methodologically, my results propose that evaluation could learn from structural prevention interventions. Applying context mapping methods could be a promising approach to better understanding adaptation and the complex associations between climate and health. Additionally, evaluation designs targeting determinants of health might be an alternative until research is better equipped to measure direct health outcomes of adaptation.

To expand the scope of adaptation, I suggest reconsidering the current sector-specific and incremental approach to climate change adaptation. To fully realize policies' potential for health protection, transformational adaptation (O'Brien 2011) should be considered. Transformation entails the opportunity to strengthen health systems and Public Health overall as it aims for broader societal change, such as re-evaluating paradigms of economic growth (O'Brien 2011), or strengthening diversity. Similar to the goal of "health in all policies," a climate change conscious approach to all relevant

health policymaking and vice versa, always examining the possibility of harm or benefits to Public Health, might contribute to a healthier future under climate change. Such an approach might be differentiated according to the level at which health policies are made, ranging from local and regional levels to national or global processes. Finally, I propose an expanded conceptualization of effectiveness that entails social justice considerations within climate change adaptation and health research.

1.4 Dissertation outline

Chapter 2: Understanding climate change, health and adaptation

This chapter focuses on the known associations between climate change and health, and on the aims of adaptation in mediating these effects. This chapter introduces the concepts of climate change, mitigation and adaptation. An overview of the specific health risks from heat is followed by insights into why evaluation is a problem when discussing climate change adaptation. Chapter 2 delivers the background information necessary to frame the complexities of adaptation evaluation targeted in the subsequent chapters.

Chapter 3: The place and vulnerability: theoretical foundations

Climate change is a global phenomenon with local effects. The local place as site of action and reaction matters in climate change adaptation, creating or reducing vulnerabilities to adverse health effects through its properties. Following an introduction to a theory of place in Public Health, this chapter describes the theoretical foundations of place-based vulnerability. Place-based vulnerability helps in understanding the role of social, cultural, and environmental determinants of health that characterize the theoretical framework for adaptation evaluation.

Chapter 4: Knee-deep in data? Reflections on data collection and analysis methods

The methods chapter delves deeper into the specific mixed methods employed throughout this study: discourse and policy analysis, situational analysis, geographical modeling, and systematic review methods. Constructivist researcher positionality, triangulation, and research ethics are discussed.

Chapter 5: Approaches to adaptation evaluation

Adaptation evaluation is targeted through five different lenses: as a systematic review of the state of effectiveness knowledge, as evaluating risk factor changes with the example of vector niche modeling, as evaluating policy, evaluation on the ground in the Japanese case study, and as reframing effectiveness through a theoretical framework development. Results of each of these studies are briefly summarized in this chapter.

Chapter 6: The problem of evaluation: a search for solutions

If adaptation evaluation is a problem, which solutions can be applied? Two main solution paths result from this research project: one methods-based and one theory-based. Current epidemiological methods to assess adaptation effectiveness could be strengthened through the testing of alternative hypotheses, as has been done in our add-on study described in the Outlook section. Using qualitative methods to map the context of adaptation is an important option as well. Drawing from Public Health knowledge, structural prevention seems to be a promising method to increase the validity of adaptation evaluation. Theory-based solutions could lie within "trans-formational" adaptation and a "health in all adaptation policies" approach. Finally, the theoretical framework describes how to assess climate justice as a proxy for direct health effects of adaptation, a solution in line with the social justice imperative of Public Health as a discipline. Methodological contributions of this work are a) assessing policy with a social justice framework and discourse analysis, b) an exploratory case study including interviews, documents and observation, and c) using open source software and data for risk factor changes evaluation. Theoretical contributions include a new,

theory-based adaptation evaluation framework, a strengthened link between climate justice and Public Health, and a reduction of inequities as an additional definition of effectiveness in the context of health and climate change adaptation.

Chapter 7: Conclusions

There is currently only inconclusive evidence for the effectiveness of specific adaptation measures. To answer the research question of how to evaluate adaptation, this dissertation proposes a multimethod approach with strong qualitative components, and the inclusion of justice considerations into evaluation. Applying climate justice and place-based vulnerability to health-related adaptation evaluation suggests a new way of conceptualizing evaluation. Future research might be conducted on alternative methods of adaptation assessment in Public Health, and on a better understanding of the role of contextual factors in health-focused climate change adaptation. Assessing the social, cultural, and environmental determinants of health from a social and climate justice perspective might be particularly beneficial in these research projects.

2 Understanding climate change, health, and adaptation

2.1 What is climate change?

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as

> *a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods* (United Nations Framework Convention on Climate Change 1992).

Their definition puts a human contribution to global environmental changes in a central role. This dissertation uses the definition of anthropogenic climate change as proposed by UNFCCC, as the role of humans in these changes matters to perceptions of risks and responsibilities for adaptation (Hulme et al. 2009; Boykoff et al. 2010). Observed and projected climatic changes provide justification for research into the effects of climate change. The climate change research community agrees that global average temperatures will rise, resulting in increased frequencies and/or intensities of extreme weather events such as heat waves and droughts, wildfires, floods, and cyclones (IPCC 2012a; IPCC 2014b). Additional effects on natural systems caused by climatic change include shifted precipitation patterns, sea level rise, ocean acidification, shifts of species distributions, and changes in crop yields (IPCC 2014b).

Short-term and long-term projections of changes are regarded as state of the art. For IPCC assessment reports (AR) prior to AR5, standard scenarios (Box 1) project future climate developments based on assumptions about economic developments, technological change, greenhouse gas emission developments, and population growth (Arnell et al. 2004; van Drunen et al. 2011; Moss et al. 2010). These scenarios were used in Boeckmann & Joyner (2014). Since 2013, these scenarios have been updated to include “shared socio-economic pathways” (SSPs), and are now replaced by the “Representative Concentration Pathways” (RCPs) (KC & Lutz 2014; van Vuuren et al. 2012; O’Neill et al. 2013; Ebi et al. 2013; van Vuuren & Carter 2013). National databases

have been established (Harrison et al. 2015). For a detailed overview over the new scenarios, refer to Van Vuuren et al. (2011) and IPCC (2013).

Box 1: *SRES scenarios*

- A1 storyline: Characterized by very rapid economic growth. Population projected to peak in mid-century, followed by decline. Emergence of new efficient technologies projected.
- A2 storyline: Regionally fragmented, slow economic growth in a very heterogeneous world with continuous population growth.
- B1 storyline: Fast economic changes towards information technology and service economy, fewer industrial emissions through resource-efficient technologies. Same population developments as in A1 storyline.
- B2 storyline: Characterized by local efforts towards sustainability, intermediate economic development and continuous population growth at a lower rate than in the A2 storyline.

Adapted from Nakicenovic et al. (2000:177-182).

2.2 Climate change impacts on health

Global environmental changes will likely fundamentally alter climatic experiences on the planet (IPCC 2014a). Within this planetary system, human beings are locally affected by the impacts of global changes. Shifts in weather patterns can lead directly and indirectly to human health impacts worldwide (World Health Organization 2012; Confalonieri et al. 2007). To illustrate *how* climate affects health, three pathways are commonly described:

- Direct impacts caused by increased frequency of extreme weather events including temperature events;
- Effects mediated by natural systems, such as vector distribution or pollen distribution;

- Effects mediated by social systems, such as increased air pollution (Smith et al. 2014:716).

Possible health outcomes influenced by climate change are presented in Table 1. Established risk factors for climate-sensitive health outcomes vary by condition and specific climate impact; however, age, socio-economic status, living conditions, and availability of social support have been identified as risk factors for heat and extreme weather events (Loughnan et al. 2010; Schwartz 2005; Cutter et al. 2014). Regarding heat, for instance, high population density, lack of green spaces in densely built environments, and cramped living conditions have been cited as risks (Klein Rosenthal et al. 2007; Uejio et al. 2011; Klein Rosenthal et al. 2014; Campbell-Lendrum & Corvalan 2007). Flooding or severe storms, conversely, might lead to greater damages in unplanned settlements or in households without diversified livelihoods (Nchito 2007; Sanderson 2000; Nelson et al. 2010).

Table 1: ***Climate change and health effects***

Climate change impacts	***Health effects***	***Exemplarily cited in***
Increased frequency or intensity of extreme temperature events	Increased mortality from cardiovascular and respiratory diseases, risk of heat stroke, increased risk of flu in cold periods	(Smith et al. 2014; Confalonieri et al. 2007; McMichael et al. 2004; World Health Organization 2014b; Nitschke et al. 2007; Hartz et al. 2012; Kjellstrom et al. 2010; Woodward 2014; Barnett et al. 2012; Hajat et al. 2014; McMichael et al. 2008; Armstrong et al. 2011; Bassil et al. 2011)
Increased frequency or intensity of extreme weather events: floods, storms, typhoons, droughts	Deaths, injuries, increased risk of trauma, destroyed infrastructure	(Smith et al. 2014; Confalonieri et al. 2007; McMichael et al. 2004; McMichael, Campbell-Lendrum, et al. 2003; Jakubicka et al. 2010; Lowe et al. 2013; Mechler et al. 2014; Sauerborn & Ebi 2012; Crabtree 2012; Ahern et al. 2005; Guha-Sapir et al. 2012; Christenson et al. 2014; Morss et al. 2011; Knutson et al. 2010)
Increased UV ray exposure	Increased incidence of skin cancers and eye cataracts	(Smith et al. 2014; McMichael et al. 2004; Confalonieri et al. 2007; McMichael, Lucas, et al. 2003; Thomas et al. 2012)
Indirect health effects, mediated by eco- and human systems		
Changes in vector distribution patterns	Increased incidence of malaria, dengue fever, tick-borne diseases in regions previously unaffected, increased prevalence in endemic regions	(Semenza & Menne 2009; Semenza, Suk, et al. 2012; Semenza, Herbst, et al. 2012; European Center for Disease Prevention and Control 2015; Morin et al. 2013; Carbajo et al. 2012; Patz et al. 1996; Dhiman et al. 2010; Bai et al. 2013; Zhang et al. 2008; Patz et al. 2014; Frumkin, McMichael, et al. 2008)
Increased pathogen loads in water or food through changes to transmission, growth, persistence or virulence	Increased risks of water- and food-borne diseases such as enteric viruses, zoonotic bacterial pathogens	(Smith et al. 2014; Confalonieri et al. 2007; McMichael et al. 2004; Semenza, Suk, et al. 2012; Kjellstrom & McMichael 2013)
Changes in pollen season and distribution	Increased prevalence of asthma and allergic rhinitis	(Smith et al. 2014; Confalonieri et al. 2007; McMichael et al. 2004; Beggs 2010; Reid & Gamble 2009; Kinney 2008)
Increased air pollution	Increased respiratory disease risks through long-term exposure to particles or acute air pollution episodes	(Smith et al. 2014; Confalonieri et al. 2007; McMichael et al. 2004; Kinney 2008; Harlan & Ruddell 2011; Beggs 2010)
Changes to crop yields	In food insecure areas, increased risk of undernutrition through higher food prices, population displacement	(Smith et al. 2014; Confalonieri et al. 2007; Schmidhuber & Tubiello 2007; Friel 2010)
Soil degradation and freshwater scarcity	Increased risk of violent conflicts over clean water sources	(Wutich & Ragsdale 2008; Salehyan & Hendrix 2014; German Federal Ministry for the Environment Nature Conservation and Nuclear Safety 2002)

Gender has not yet been conclusively connected to risk mediation for specific health effects of any climate impact in higher income countries (Alston 2010; Dupont 2012; Arora-Jonsson 2011), although it does play a role in mediating vulnerability, not only in food and water insecure regions (World Health Organization 2011; Stott 2010; Terry 2009; Watt & Chamberlain 2011; Kakota et al. 2011; Chavez Rodriguez 2013).

Despite a steadily increasing interest in the health effects of climate change (Hosking & Campbell-Lendrum 2012), the pathways through which climate affects health beyond the direct/indirect dichotomy are still not entirely understood. This is particularly the case for non-communicable diseases. While impacts of climate change on mental health outcomes have been suggested (Page et al. 2007; Dixon et al. 2007; Berry et al. 2010; Berry 2009; World Health Organization Centre for Health Development 2009; Hansen et al. 2008; Crabtree 2012), these are especially difficult to attribute to thermal stress and extreme events (Smith et al. 2014; Gosling et al. 2009). This connects with this dissertation's research focus, as it implies a "problem" of evaluating the mediating effects between climate change and health outcomes.

Within environmental health, climate change fills a unique position. The dose-response relationship concept used e.g. in toxicological research can potentially be applied to heat (Dessai 2002; Jackson et al. 2010; Schwartz & Zanobetti 2000), but not easily to additional climate impacts (McMichael 2013). Epidemiological relevance of the effects of temperature extremes on health outcomes has been established through various studies, the majority conducted in higher income nations (Armstrong et al. 2014; Borbora & Das 2014; Ono 2012; McGeehin & Mirabelli 2001; Hartz et al. 2013; McMichael et al. 2008; World Health Organization 2006; D'Ippoliti et al. 2010; Leone et al. 2013; Woodward 2014; Anderson & Bell 2009; Gabriel & Endlicher 2011). As temperature-related health effects are expected to continue to play an important role in the health profiles of both higher and lower income countries in the future (Ballester et al. 2011), the following section discusses the physiological effects of heat on the body,

risk factors for heat-related medical conditions, and the epidemiology of heat-related morbidity and mortality.

2.2.1 Heat as a hazard: medical risks of heat

Burton called heat the "pervasive hazard" (Burton, 1978:31). Adverse heat effects can occur from hours to days after an extreme period of heat: these lag effects contribute to the "pervasiveness" of heat. Extreme heat is characterized by a deviation from the average. The classification of hot weather as an extreme temperature event depends both on the duration and on the intensity of the event (Kovats & Hajat 2008). How many hot and humid days occur in a row, and how hot and humid are they? For both the length of a heat event and its intensity, a location-specific threshold needs to be exceeded for it to be classified as a heat wave (Kovats & Hajat 2008; Gosling et al. 2009). No fixed worldwide threshold exists (United States Environmental Protection Agency 2006), as the average conditions for the specific time of year vary spatially and temporally. The criteria for extreme heat have to be specified by each location (United States Environmental Protection Agency 2006). Consequently, the standard definition of a heat event is "a prolonged period of unusually hot weather" (D'Ippoliti et al. 2010), and different definitions have been used in impact assessments. While the largest increases in temperature extremes are projected for cities in temperate regions (Patz et al. 2005), subtropical and tropical regions are also vulnerable (IPCC 2014a).

Quantitative evaluation of the impacts of heat on human health is usually done with time-series or case-crossover designs (Huang et al. 2011). Studies need to ideally control for trends, seasonal cycles in mortality, humidity, and air pollution. Data on the burden of heat-related illness and mortality are not routinely collected: individual health agencies may monitor ambulance dispatches, heat-related hospitalizations, or excess deaths during heat events (United States Environmental Protection Agency 2006). Exact numbers of excess mortality and heat-related morbidity are therefore highly location-specific and not regularly published as global or even national averages. Instead,

projections of attributable mortality are used to illustrate the necessity for adaptation. The 2014 World Health Organization (WHO) report on the quantification of climate change-related causes of death estimates an average of 92 207 heat-related excess deaths worldwide annually by 2030 under a no adaptation scenario (World Health Organization 2014b:23).

Increased mortality risks have been observed for both extremely high and low temperatures (Chung et al. 2009; Nitschke et al. 2007; Tobias et al. 2014; Bobb et al. 2014; Guo et al. 2014). Previous studies have discussed the existence of intra-city climates and climatic differences between cities that also lead to location-specific heat thresholds (Goggins et al. 2012; Tobias et al. 2012). A heat threshold indicates an upper limit before effects on health occur. Comparability between studies on thresholds is compromised as the term "temperature" is used inconsistently and ranges from maximum air temperature to median of air temperature plus humidity, or from apparent temperature to heat indices.

2.2.2 Physiological effects of heat

The human body relies on a consistent internal temperature of 37°C to ensure functionality and protect vital organs (Yeo 2004; United States Environmental Protection Agency 2006). Both excessive hot and cold temperatures over a prolonged time period are potentially lethal, leading to hyperthermia and hypothermia, respectively (Yeo 2004). Heat-related medical conditions progress from heat cramps and heat exhaustion to heat stroke and possibly multi-organ failure and even death (United States Environmental Protection Agency 2006; Yeo 2004; Alberini et al. 2011; Bi et al. 2011; Bouchama & Knochel 2002; Bouchama et al. 2007). Heat stroke is associated with death in 10%-70% of all cases, a wide range mediated by age of the patient and duration until treatment (Yeo 2004). Additionally, heat exacerbates circulatory diseases through the thickening of blood as a result of dehydration and subsequent extra strain on the heart: the heart must work harder to increase circulation to cool down the body (United States

Environmental Protection Agency 2006; Donaldson et al. 2003; Keatinge et al. 1986). Extreme heat has been linked to indirect effects as well: increased incidences of suicide, injuries, violence, and crime have been reported (Bi et al. 2011; Dixon et al. 2007; Lee et al. 2006; Page et al. 2007; Preti et al. 2007). However, interpretation of the associations between mental health outcomes and heat needs to be approached cautiously, as conclusive evidence is not yet available and might be difficult to establish (Berry et al. 2010).

2.2.3 Risk factors for heat-related illness and mortality

Several risk factors for heat-related medical conditions have been identified. Experts differentiate between exertional and non-exertional heat stroke, where the first is a result of strenuous physical activity in a hot environment (Yeo 2004). Athletes and workers in factories or outside are most likely to experience exertional heat stress (Adam-Poupart et al. 2013; Sheffield et al. 2013; Yeo 2004; Jackson & Rosenberg 2010). Regarding classic heat-related illness, both very young children and persons 65 years or older are more likely to experience ill effects of heat (Yeo 2004; Bouchama & Knochel 2002; United States Environmental Protection Agency 2006; Kovats & Hajat 2008). In children, the ability to thermoregulate is not completely developed (Kovats & Hajat 2008). Among older persons, impaired thermoregulatory systems in the brain increase risks (Kovats & Hajat 2008). In addition to age, other physiological risk factors include preexisting health conditions, obesity, dehydration, and alcohol abuse (Kovats & Hajat 2008). Risk of *death* from heat stroke is associated with an inability to leave the bed or the house, and inability to care for oneself (Bouchama et al. 2007). Preexisting conditions increase the chances of dying from heat stroke, in particular severe psychiatric illnesses, and cardiovascular and respiratory diseases (Bouchama et al. 2007). The link between mental health and risk factors likely depends on the ability to take precautions during a heat event, and on the characteristics of psychotropic medications that may interfere with thermoregulation (Bouchama et al. 2007; Hajat et al. 2010). Diuretics, antianginal drugs, or beta blockers may also aggravate risks in

patients with preexisting illnesses (Hajat et al. 2010).

The physiological risk factors for heat-related morbidity and mortality are exacerbated by social and environmental determinants (Banwell et al. 2012; Kovats & Hajat 2008; Bouchama et al. 2007; Yeo 2004). Particularly the built environment, access to cool places, exposure to sun, and protective behaviors mediate the effects of heat (Hajat et al. 2010; Kovats & Hajat 2008; Yeo 2004; Laaidi et al. 2012; Harlan et al. 2006). Previous research suggests drinking more fluids, taking additional showers to cool off, reducing physical activity, and spending time in an air-conditioned or cool environment as behavioral interventions (Hajat et al. 2010). However, these recommendations have also been associated with adverse effects (Bouchama et al. 2007). The use of electric fans to cool air is particularly debated, as re-circulating warm air within a closed room may even increase the risk of heat stress (Hajat et al. 2010; Gupta et al. 2012; Bouchama et al. 2007). Disagreement also exists on whether social capital and social networks increase or decrease risks for elderly persons: studies have shown that older persons do not always perceive themselves to be vulnerable to health risks in extreme heat (Wolf et al. 2010; Abrahamson et al. 2009). Strong social networks may strengthen this belief and subsequently prevent people from seeking help or adapting their behavior during a heat spell (Wolf et al. 2010). On the other hand, Bouchama at el. (2007) observed an association between increased social contact and better health outcomes during heat waves.

2.2.4 Anatomy of a place-based risk: the built environment and heat

What transforms urban surroundings into risky locales for heat-related medical conditions? First, lower socio-economic status is associated with lower quality housing. Living in inadequately ventilated, densely populated areas in urban centers with lack of air conditioning are all factors that increase chances of heat exposure (Yeo 2004). In addition to substandard housing conditions, city areas with vulnerable electricity provision, fragile transportation infrastructure, and overwhelmed healthcare facilities

extend social disadvantages to heat and health outcomes (Klein Rosenthal 2010). Second, higher air and surface temperatures in cities as opposed to rural or suburban areas result from an "interaction between urbanized land use and the atmosphere" (Klein Rosenthal, 2010:22). Heat can be trapped between buildings, as artificial surfaces on buildings and streets absorb sunlight and store and reflect heat (Klein Rosenthal 2010). This "urban heat island effect" (UHI) is a major risk factor for adverse effects on health during heat events (Harlan et al. 2006; Glutting 2011; Tan et al. 2010; Oliveira et al. 2011; Takebayashi et al. 2014; Klein Rosenthal et al. 2014; Gabriel & Endlicher 2011).

Additionally, living in areas with high criminal profiles or few communal spaces might make it difficult for older people and people with disabilities to leave the house. As a result, access to cool public spaces such as air-conditioned shopping malls, public pools, or community centers might be compromised (Wolf et al. 2010). Eric Klinenberg famously illustrated how social and cultural environments shape susceptibility to heat in the 1995 Chicago heatwave, during which people of color and poorer city dwellers were disproportionately affected (Browning, Wallace, Feinberg, & Cagney, 2006; Klinenberg, 1999, 2006; see also Morello-Frosch et al., 2011 for intra-city racial and social disparaties in environmental health). Similar intra-city differences in heat-related morbidity and mortality outcomes have been described for other large cities in the United States (Klein Rosenthal et al. 2014; Klein Rosenthal 2010; Klein Rosenthal et al. 2007; Tomlinson et al. 2011), Europe (Glutting 2011; Oliveira et al. 2011; van der Woerd et al. 2012), and Asia (Tan et al. 2010; Chang et al. 2007; Takebayashi et al. 2014; Borbora & Das 2014; Azhar et al. 2014). Inequities thus mediate risks from heat (Friel et al. 2011).

2.2.4.1 Urbanization as a risk factor

Owing to their unique risk profile, cities are of special interest to this dissertation research. This is fueled by the global urbanization development: In 2010, 29% of the urban population lived in cities with more than 1 million inhabitants, 10% of the urban

population lived in megacities of more than 10 million inhabitants (United Nations Department of Economic and Social Affairs Population Division 2014). While there are fewer such megacities in Europe and North America, the overall urbanization trend is observable on all continents (United Nations Department of Economic and Social Affairs. Population Division 2014; UN-HABITAT 2013). For instance, land cover changes from green spaces such as parks to asphalt or otherwise built areas has increased, among others, in Europe and the United States (McCarthy et al. 2010; Stone et al. 2010; Kalnay & Cai 2003; Vargo et al. 2013). Overall, the prevalence of UHI has increased in the past decades, increasing the risk of extreme heat in urban centers (Lim et al. 2005). Choice of study regions in this dissertation was driven by these considerations.

2.3 Dealing with climate change: adaptation

What is adaptation? The term refers to adjustments made in relation to environmental variability (Janssen & Ostrom 2006) and can denote both planned adaptation and biological acclimatization. "Adaptation" as a concept consequently appeared in anthropological research as early as the 1900s, yet these roots are rarely acknowledged in current climate change research (Janssen & Ostrom 2006). Human adaptation in the climate change context has been defined by the IPCC as

> *the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.* (IPCC 2012b:3)*.*

This basic definition is also the working definition in this dissertation, yet here only planned adaptation is of interest. Autonomous adaptation as unconscious choice is hardly influenced by interventions (van de Sand 2012). This work is further informed by the added dimensions of incremental and transformational adaptation (Kates et al. 2012). Incremental adaptation refers to smaller scale changes that are slight deviations from current practice (Kates et al. 2012). Transformation, on the other hand, implies substantive changes to the status quo, for instance through invention of completely new solutions or through systemic changes (O'Brien 2011). Kates et al. (2012) differentiate between three types of transformational adaptation: adaptation of larger scale and

intensity than before, adaptation never before implemented in a region or system, and adaptation processes changing locations. Karen O'Brien stresses the opportunity for "psycho-social" change processes in human systems inherent to transformational adaptation, driven by the ultimate goal to achieve a "better life" (O'Brien 2011:670). Examples of transformational approaches include campaigns to strengthen gender equity, or increased North-South exchanges on green technology, as have been described in national adaptation policies in Boeckmann & Zeeb (2014). Until now, such strategies exist mostly on paper, and active implementation is less common.

Adaptation differs from mitigation by focusing on dealing with inevitable changes in the global environment, whereas mitigation aims at minimizing the likelihood of climatic changes through "human intervention to reduce the sources or enhance the sinks of greenhouse gases" (Edenhofer et al. 2014:37).

2.3.1 Research into adaptation and health

The umbrella term adaptation contains a number of measures that vary between disciplines and goals: from economics to development aid, from urban planning to the health sector. Any aspect of human society could be targeted by adaptation, yet so far few large scale research projects specifically assessing health in the context of adaptation have been conducted. The joint World Health Organization/ World Meteorological Organization office for climate change and health, for example, was conceived of as recently as 2014. The European Commission (EC)-funded CIRCLE-2 ERA[1] project, recently concluded in April 2014, was a "Climate Impact Research & Response Coordination for a Larger Europe," promoting research funding and cooperation for climate change impact and adaptation research. The project was mainly interested in collecting examples from adaptation practice in participating countries and was not specifically aimed at health research. Its database does allow searches for health-related adaptation research or practice: the free-text search for "health" reveals 131 project entries as of October 2014. A second 7th framework funded European project,

[1] www.circle-era.eu

RESPONSES[2], focuses on European climate change policy, including both mitigation and adaptation. Only one explicitly health-related publication can be linked to the large recent project output (Bouzid et al. 2013). Research on health *impacts* is more abundant: Targeting human health and heat more specifically, the ISOTHURM project examined heat- and cold-related mortality in urban populations in non-OECD countries (McMichael et al. 2008). Their findings suggested a universal vulnerability to heat in all cities, with a higher impact of extreme events in warmer climates (McMichael et al. 2008). Similar findings on impacts were published from the EUROHeat and PHEWE projects for European countries (D'Ippoliti et al. 2010; World Health Organization 2006; Baccini et al. 2011).

Beyond these lighthouse consortia, a large number of studies on the effects of heat on health exist (see section on climate change and health above), yet few studies have looked at the effects of *adaptation* to heat on health (see, for instance, Bobb et al. 2014 on air conditioning and long-term mortality). Research into anthropogenic climate change adaptation started in the 1990s, and was first synthesized in the 2nd IPCC assessment report from 1995. It follows that the concept of adaptation was neither originally developed for the Public Health context, nor can health researchers draw on a long tradition of adaptation research. Where early studies focused on developing a theoretical conceptualization of adaptation (e.g., Smit et al. 2000), in recent years empirical papers have largely superseded theoretical articles (Berrang-Ford et al. 2011; Biesbroek et al. 2010; Lowe et al. 2011; Wolf et al. 2014; Martinez et al. 2011; Heimann & Christmann 2013). To a lesser extent theory-based papers are still being published (Christmann et al. 2012; Wise et al. 2014). One question is whether this replacing of theory with policy assessment studies cuts short a theorizing of adaptation specifically for health and its evaluation. The roles of contexts and systems in adaptation design for health protection, for example, need to be further examined.

Regarding non-health specific adaptation research, however, an active international

[2] http://www.responsesproject.eu

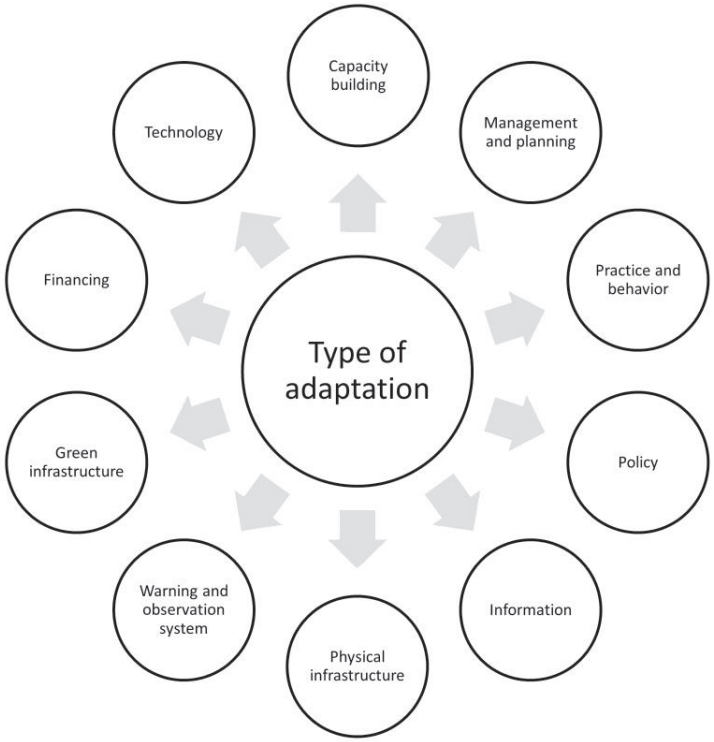
research community can draw from European funding, and new knowledge is expected for the near future. To highlight only a few efforts, three European Commission funded projects, "Bottom-Up Climate Adaptation Strategies for a Sustainable Europe" BASE[3], RAMSES[4] on urban climate impacts, and "Tool-supported policy development for regional adaptation" (ToPDAd)[5] support the 2015 European Climate Change Adaptation Conference (ECCA). As of this writing, neither of these projects showed an explicit commitment to human health related research, however.

2.3.1.1 Adaptation typologies

Various types of adaptation measures have been described. Biagini et al. (2014) listed ten categories of adaptation actions (Figure 1). This typology was derived from adaptation measures undertaken in actual funded projects. It thus gives a sufficient overview of what is being done, yet other types of adaptation are possible as well. The fragmentation, however, makes it difficult to pinpoint the underlying principles of these types. Alternatively, in the critical policy analysis article we simplified the typology to four main strands describing the main categories of current adaptation practice: technological, behavioral, surveillance, and infrastructural. Additionally, Biagini et al.'s typology (2014) draws artificial lines: most of the described options are usually backed by policy, both infrastructure and warning systems influence behavior, and none are possible without financing.

[3] http://base-adaptation.eu
[4] http://www.ramses-cities.eu
[5] http://www.topdad.eu

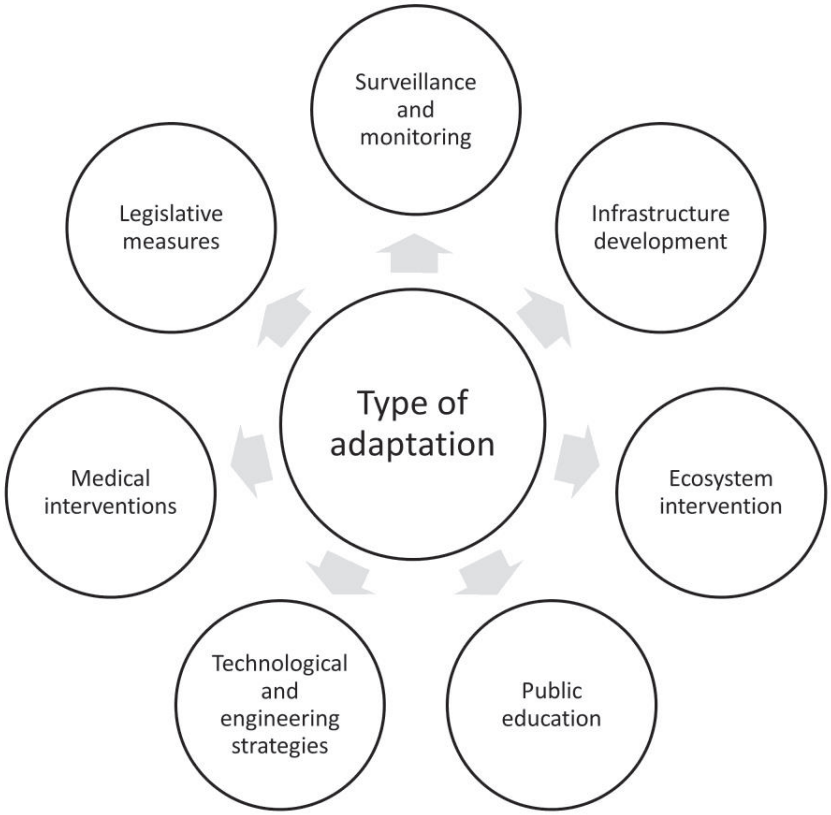
Figure 1: ***Biagini et al.'s (2014) ten adaptation types***



Adapted from Biagini et al. (2014).

Conceptual frameworks for adaptation are numerous, and it has been suggested that individual adaptation projects should combine relevant inputs from several frameworks for a better situation-specific fit (Füssel & Klein 2004; Füssel 2008; Smit et al. 2000; Hinkel et al. 2013). Health-specific typologies typically resemble the above mentioned categories, as exemplified by Füssel & Klein (2004) (Figure 2).

Figure 2: ***Examples of health-specific adaptation types***



Adapted from Füssel & Klein (2004), Balbus et al. (1998), McMichael & Githeko (2001).

2.3.1.2 Adaptation measures and strategies

Specific adaptation measures are even more numerous than the overarching types. Any approach to prepare systems for pressures caused by climate change could be defined as climate adaptation measures. For the health sector, the U.S. Environmental Protection Agency (EPA) and the U.S. National Research Council suggest implementation of warning systems, emergency response plans, and urban greening as such measures (America's Climate Choices: Panel on Adapting to the Impacts of Climate Change et al. 2010). Additional options include disease vector monitoring (Thomas et al. 2014; Semenza, Suk, et al. 2012), increasing awareness among health professionals (Sawford et al. 2014; Walker et al. 2011), or investing in flood protection (Haque et al. 2012;

Garrelts & Lange 2011; World Health Organization Regional Office for Europe 2002; Keim 2008). Those measures are not necessarily led by the health sector: within climate adaptation, intersectoral approaches are necessitated by the truly trans-sectoral impacts of climate change (Ebi & Burton 2008). A standard adaptation portfolio most likely contains a warning system, a monitoring or surveillance approach, physical infrastructure fortification, and awareness raising campaigns (Boeckmann & Zeeb 2014; Biesbroek et al. 2010). All measures depend on the climate change impacts they are supposed to target, and on the perceived importance of each climate-related health risk. Public Health adaptation thus occurs where the risks of climatic impacts on human health are recognized and targeted: climate change adaptation could be framed as a complex Public Health intervention (Ebi 2009; Frumkin, Hess, et al. 2008; Hess, Schramm, et al. 2014). As stated before, climatic changes are expected to both bear new risks (e.g. expansion of disease vectors to previously inhabitable geographic areas), and to increase pressure from current health risks (e.g. increased frequencies of extreme temperature events). Strengthening basic Public Health services and targeting current access to care inequities has been proposed (Smith et al. 2014). In addition, raising awareness among stakeholders and the public continues to be an important aspect of adaptation (Das & Smith 2012; Lane et al. 2014; Halady & Rao 2010; Sawford et al. 2014).

Adaptation policy has, until now, often been developed without clear theoretical understanding of how it is supposed to work (Ford et al. 2013). The abundance of adaptation guides for the development aid context illustrates this problematic gap: NGOs, governmental aid agencies, and similar organizations have published a high volume of manuals on how to design and monitor adaptation projects based on their daily work (van de Sand 2012; Bours et al. 2013). These community-based projects are usually aimed at poverty reduction, economic adaptation, and adaptation to natural hazards without a specific health focus (Barrett 2013). Their focus is not easily transferred to higher income nations, although the idea of community-based actions

bears potential regardless of location (United Nations Centre for Regional Development 2003; Picketts et al. 2013; Ireland & Thomalla 2011). Practice-based manuals are of high value; yet specifically for Public Health research theoretical frameworks on how adaptation is supposed to protect health are equally necessary. One possibility would be to frame adaptation as a precautionary principle, intended to prevent harm to health. The question then has to include how unintended harmful or beneficial effects of adaptation can be included in evaluation. These questions have not been answered. One possibility for a theoretical framework is suggested in this dissertation.

2.3.2 Global adaptation governance

International adaptation policy is generally characterized by slow progress, partially caused by relying on voluntary commitments of countries and their governments (Ayers 2011; SEI 2012; Patt 2012; Arnell et al. 2013). The UNFCCC, the most relevant climate change related international treaty (Böhmelt 2013), was negotiated in 1992, but the subsequent Kyoto Protocol's first commitment period did not start until 2008 (United Nations Framework Convention on Climate Change 2014a). In the UNFCCC's adaptation work stream, knowledge generation and, more importantly, financial compensation mechanisms between countries play an important role (United Nations Framework Convention on Climate Change 2014b). Overall, the UNFCCC process is less interested in health issues and geared more towards reducing greenhouse gas emissions, and strengthening lower and middle income countries' responses (Burton et al. 2002). The potential mismatch between global governance of climate change and local susceptibilities to the effects of these global developments has been called an "adaptation paradox" (Ayers 2011; Ayers 2010). This leads to concurrent implementation of national, regional, and local climate change adaptation strategies, under various leaderships and with various goals (Wiley 2010). At the global level, climate diplomacy has established international protocols and meetings such as the Conference of the Parties of the UNFCCC (Schipper 2006). National and local adaptation efforts by governments or stakeholders are needed to complement global arrangements

(Panic & Ford 2013), as is represented in the policy analysis of national documents and the Japanese interview study.

2.4 The "problem" of evaluation

In this study, evaluation refers to the question: *"How can we assess whether climate change adaptation reduces adverse health effects?"* The challenges associated with measuring adaptation and health together create the "problem of evaluation." This problem of evaluation has four reasons:

1. climate change is a complex problem that manifest itself through disparate impacts at varying spatial and temporal scales,
2. climate change occurs in the post-normal science realm,
3. the black box of context,
4. challenges attributing causality in place-based vulnerability to heat and other climate effects.

Ideally, health-related evaluation of climate change adaptation should be able to reconcile different understandings of effectiveness between epidemiology and public policy.

Climate change is such a wicked problem because its effects seem "distant, intangible and delayed" (Feliciano and Berkhout 2013:415). The current world, with its complexity, uncertainties and global risks has been termed the "post-normal age" (Funtowicz & Ravetz 1993), where uncertainty cannot be reduced or dismissed. Instead, uncertainties have to be accepted and managed (Funtowicz & Ravetz 1993; IPCC 2012a). This concept applies to climate change in that a) the uncertainties inherent to projections, scenarios, pathways, and estimates are a fundamental part of climate change, and b) solutions are urgently needed because of these complexities and uncertainties. Related to complexities is the idea of a black box of context (Broadbent 2011b; Macintyre et al. 2002). The term describes the difficulties researchers have in separating individual contextual factors from the entire context. What role does each of these factors play?

What about a cumulative effect of context? Answering these questions has been challenging. Finally, identifying causal relationships remains the main crux of adaptation and health research and is discussed further in the next section.

2.4.1 Evaluating adaptation

Spearman & McGray (2011) argue that strict evaluation frameworks from other contexts might prove insufficient to capture the effects of adaptation. The keyword is "causal link": to assess whether the adaptation measure protects human health, a causal link between the measure and a chosen health outcome needs to be established. This causal link is a major challenge in climate change adaptation research due to:

- the long timeframe from implementation to societal changes,
- the difficulty establishing the counterfactual or control,
- the novelty of adaptation projects,
- and the multiple pathways through which a) diseases, especially non-communicable illnesses, develop, and b) adaptation policy influences determinants of health that may contribute to disease etiology themselves.

Additionally, determining what to measure when assessing adaptation is debated (Panic & Ford 2013; Ford & Berrang-Ford 2015). Do outcomes or process matter more? My case study showed that adaptation in itself often demarcates only the beginning of a process and may not necessarily go by the name of climate adaptation. Whether one should assess changes in vulnerability, or resilience, or adaptive capacity, or use indicators for all of these, remains entirely up to the researcher (Ford et al. 2013; Lamhauge, Lanzi, and Agrawala 2013). Uncertainties about how to evaluate adaptation outside the development context, specifically for Public Health, drive this research project. On a positive note, these uncertainties allow researchers to explore the issue using different methods.

As shown, previous research exploring adaptation evaluation draws heavily from disaster risk reduction and livelihoods research in developing countries (Nielsen &

Reenberg 2010; Rosenthal & Jessup 2009; Campbell-Lendrum & Corvalan 2007; Solecki et al. 2011). Cost-benefit analyses are an additional option for adaptation evaluation, as illustrated by a "saved wealth, saved health" formula including the disability adjusted life year (DALY) measurement (Köhler & Michaelowa 2013). Indicators are project-specific and can range from number of deaths during a heat event to number of people receiving information on risks (Lamhauge et al. 2013), with a strong focus on process (Ford et al. 2013). The ideal of a standard evaluation framework comprising a fixed set of indicators seems unlikely to sufficiently grasp the contextual and systematic differences between adaptation situations. What can Public Health contribute to solving this dilemma? How does evidence-based Public Health handle these attribution issues?

2.4.2 Evidence-based Public Health and adaptation

Of high interest to the climate change adaptation and health communities is the possible application of evidence-based Public Health (EBPH) frameworks to adaptation (Hess, Eidson, et al. 2014). Ideally, all health-related programs are steeped in evidence for their effectiveness. "First, do no harm" applies not only to medical specialists but also to well-meaning Public Health interventionists. Evidence-based Public Health aims at creating and judging this usefulness and effectiveness. This concept is defined as

> *a Public Health endeavour in which there is an informed, explicit, and judicious use of evidence that has been derived from any of a variety of science and social science research and evaluation methods* (Rychetnik et al. 2004:538).

Evidence-based Public Health seeks reliable information generated according to guidelines on what evidence entails in the health research community. Jeremy Hess et al. (2014) proposed to use a standard evidence-based Public Health framework with slight modifications in adaptation research. The framework has potential, but is also confronted with the problem that standard hierarchies of evidence from evidence-based medicine cannot apply to a situation where randomized controlled trials (RCTs) are rarely done or even possible. Evaluation in Public Health is defined as

> *a process that attempts to determine as systematically and objectively as*

> *possible the relevance, effectiveness, and impact of activities in the light of their objectives* (Porta & International Epidemiological Association 2008:86).

This process is aided by evaluation tools. The choice of quantitative and qualitative tools should be driven by the specific questions the evaluation tries to answer (Bortz 2006; Kuckartz et al. 2008). Where medical research evaluates etiology and clinical effectiveness, Public Health researchers are interested in intervention evaluation and possibly policy assessments (Rychetnik et al. 2002). Similarly, climate change adaptation can be framed as either an intervention or a policy (Ebi & Burton 2008; Carter 2011; Brooks et al. 2013). Both outcome and process evaluations can be applied to Public Health research questions. Process evaluations have been a staple of adaptation policy evaluation in recent years (Marinucci et al. 2014; Füssel & Klein 2004), whereas epidemiological studies prefer to look at adaptation outcome indicators such as mortality (e.g., Aida et al. 2011; Anderson, Dominici, et al. 2013; Bi et al. 2011).

One underexplored option would be to learn from efforts of including intersectionality in epidemiological analyses (Bauer 2014). The theory asserts that multiple inequalities from all domains of social position, including sex and gender, race, ethnicity, education, age or socio-economic status, cannot be assessed as distinct since they occur simultaneously and are not additive (Bauer 2014). Intersectionality's similar need to address complex contextual domains is increasingly considered in epidemiological and medical research, and could inform adaptation evaluation methods as well.

Conceptualizing of health-related evaluation of climate change adaptation is therefore not yet complete. The goal of this work is to contribute to expanded understandings of the concepts of evaluation and effectiveness within the climate change adaptation and Public Health nexus.

3 The place and vulnerability: theoretical foundations

This dissertation is composed of five studies that examine the issue from different angles. Beyond this fragmentation, however, this dissertation is anchored in an overarching theoretical position: An understanding of human vulnerability to climate effects embedded in a theory of physical and social place. This forms the backbone of my assessments of climate change adaptation policy and human health. The two major theoretical foundations for the dissertation research project as a whole are a) the place in Public Health and climate change research, and b) theories of vulnerability.

3.1 The place in Public Health and climate change research

Place matters in health, climate change, and adaptation (Wilhelmi & Hayden 2010). Place is not limited to a geographical definition. In this research project, place is multi-faceted. People are embedded in environments composed of multiple places where they live, work, and spend free time. Depending on duration and intensity of contact with an environment, exposure to variables within these environments is stronger or weaker (Hess et al. 2008). This is confounded by humans moving between places, making themselves susceptible to the realities of more than one place. The physical location is in itself subject to changes, both subtly and on a larger scale. In climate change and disaster research, physical location can also indicate permanent exposure to place-specific disasters or climate risks (Wisner et al. 2004; World Health Organization 2002). The same holds true for Public Health risks from environmental exposures: proximity to emissions-producing factories or toxic waste in water sources can be permanent or eclectic. Places change: they expand, contract, become more or less green, contain fewer or more inhabitants, are built higher or torn down. In climate change research, this moving within one defined space is less of a problem as long as the exposure of interest, for example, the hazard, affects the defined space in its entirety. If the scale of place to be researched is thus small enough, further subdivision into more or less vulnerable areas is not necessary. If, however, the defined space is larger than the reach of the hazard, or if highly localized places have certain charac-

teristics that may confound the impact of an extreme event, then a more detailed examination of small-scale vulnerabilities and the environments creating them is required.

Environmental health research is interested in the complex interactions between environmental exposures and health outcomes. Levels of an exposure and subsequent responses are examined to assess the extent of environmental risks. With climate change and heat, such an assessment is less direct than with a toxicological substance. Fekete (2010:18) described exposure as a "measure of susceptible elements within a region threatened by a hazard." Applying his definition to heat and health, heat as the hazard becomes magnified by elements such as the built environment. Susceptibility is two-fold: while the place may be susceptible to trap heat, for instance, humans, already biologically susceptible to heat effects, might have their susceptibility magnified within said place. Consequently, the physical place mediates exposure.

3.1.1 Defining a place

How then, could one meaningfully define a place for the purposes of this research project? One option is to move beyond physical location and include broader aspects of place into the definition (Macintyre et al. 2002; Cummins et al. 2007). Beyond its physical properties, Sally Macintyre et al. (2002) include infrastructural and social aspects of place into their research on measurement of place effects on health. All three facets are relevant for the discussion on health risks of heat: exposure to extreme heat is mediated by physical and infrastructural determinants, and risk perception and behavioral adaptation rely on social functioning. Geographical patterns of health and illness are increasingly recognized as a major explanatory variable for prevention research (Keene & Padilla 2014; Morris 2010; Cummins et al. 2007; Harlan et al. 2013). In climate change discourses, the concept of climate justice is strongly linked to place as well (Bolte 2012; Sovacool 2013; Yamada & Galat 2014).

3.1.2 Black boxes of place

Macintyre et al. (2002) indicated a concern with the contextual determinants of health and argue that the mechanisms of these contexts' role in influencing health behavior and health are rarely theorized. Similar to Broadbent's critique of "black boxes" in epidemiological causation explanations (Broadbent 2011b), Macintyre et al. (2002:131) struggle with unspecific descriptions of context in health and place research, calling the lack of theorizing of context in geographic health research a "black box of places." The authors are particularly interested in what all is subsumed under "context" instead of being accounted for as individual variables. The contents of this black box, the place-related context, then, "somehow […] influence […] some aspects of health, health-related behavior, or health risks in some population groups." (Macintyre et al. 2002: 129). The authors argue that rather than view context as a single entity, it would be preferable to divide it up into compositional, contextual, and collective concepts (Macintyre et al. 2002; Macintyre 1997). Each of those three contains multiple explanatory factors:

> *Compositional explanations draw our attention to the characteristics of individuals concentrated in particular places; contextual explanations draw our attention to opportunity structures in the local physical and social environment collective explanations draw our attention to socio-cultural and historical features of communities. This last type of explanation emphasizes the importance of shared norms, traditions, values, and interests, and thus adds an anthropological perspective to the socioeconomic, psychological, and epidemiological perspectives often used to examine area effects on health* (Macintyre et al. 2002:130).

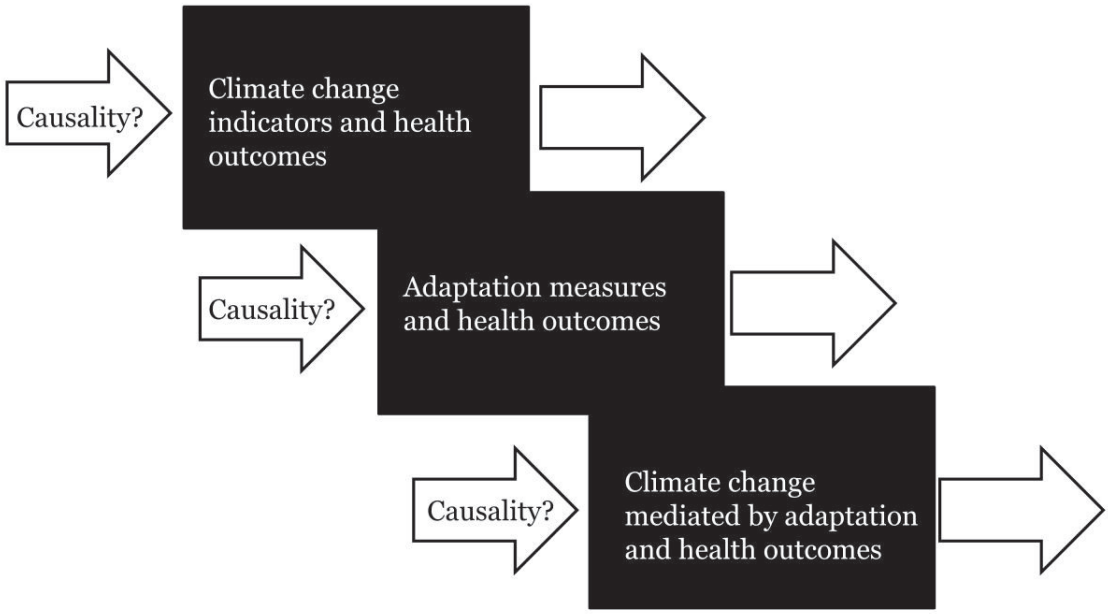
The quote illustrates the broader definition of place advocated for above. Furthermore, Macintyre et al. (2002) show how multiple variables potentially influence health outcomes in research on health and environment. I argue that this variety of factors also applies to climate change and health research. Thus the place needs to be included in any discussion on climate change adaptation.

3.1.3 Causality hidden inside black boxes

Macintyre et al.'s "black boxes of places" (2002) remind of an implicit causality: an assumption based on observational evidence of a connection that we cannot quite grasp (yet). Implicit associations have been the subject of a lively debate in the sciences; whole volumes of writings on causality concepts have been written (Illari 2011). Why is causality so relevant to climate change adaptation and health research? In this research field, we are faced not only with a black box of context and causal relationships between specific climate change indicators and health outcomes. An additional layer is created from a second black box of causal associations between adaptation efforts themselves and health outcomes, and yet a third layer of relationships between adaptation as a mediator of climate change indicators and health effects (Figure 3).

To disentangle factors and outcomes, clear definitions of the context of the research project, the exposure, and the health outcomes of interest is necessary and challenging. In addition, not only can a health outcome illustrate adaptation effects, but the way adaptation strategies shape vulnerability *determinants* matters, too. Thus it is important to remember that a) measuring context in itself is challenging, and b) causal relationships between adaptation and health are what we would like to measure. Particularly for morbidity and non-communicable disease mortality, this specific relationship poses an even greater challenge to research than other epidemiological associations caused by the frequently long timeframe between exposure and disease etiology and multiple causal pathways. Constant climatic exposure cannot easily be controlled for (Kjellstrom et al. 2010). Climate-sensitive health outcomes such as vector-borne diseases and temperature-related deaths are easier to link to climatic changes than non-communicable diseases, for instance (Campbell-Lendrum & Woodruff 2007).

Figure 3: ***Black boxes of causal relationships between climate change, adaptation, and health outcomes***



3.1.4 Place matters

As stated above, humans shape and are shaped by the places they live in. The social and physical place by and in itself constitutes a risk factor (Cutter et al. 2003). Vulnerability to environmental hazards, such as heat, is mediated by place (Wisner et al. 2004). While climate risks per se might be similar in different places, research into disasters and vulnerability has shown that the event is less relevant than conditions on the ground, including social, cultural, environmental and similar aspects (Wisner et al. 2004; Wisner 2007). Local conditions mediate effects and potential damages of a climatic event (Tierney 2012). Place as a major contextual factor thus determines appropriateness and possible effects of climate adaptation, and needs to be considered in adaptation evaluation.

Consequently, this research project repeatedly focusses on place: including in the changes in risk factor distribution study (Boeckmann & Joyner 2014), the Japanese case study (Boeckmann 2015a), and the European national policy analysis (Boeckmann & Zeeb 2014).

3.2 Health and place-based vulnerability

The concept of place-based vulnerability derived from research into social vulnerability and aims to capture the geographical and social dimensions of susceptibility to hazards (Cutter 1996; Cutter et al. 2003; Cutter et al. 2014). Cutter et al. (2014) describe their approach as appropriate to show both the location of vulnerability (the geographic dimension) and the vulnerable populations themselves (the social dimension). Their integrative concept combines biophysical exposure risk and social response within a specific place. For instance, the natural hazard heat is as much a "hazard of place" as it is a physical hazard (Cutter 1996). Cutter's theory lends itself to climate change adaptation and health research as arguing that, while developed within human geography and fundamentally geographically centered, place can either be a geographic area or social space (Cutter 1996). This is in line with the role of place discussed in the previous section. In its more recent version, this framework has been refined into a "hazards-of-place model of vulnerability" (Cutter et al. 2003:243), in which a "hazard potential is either moderated or enhanced by a geographic filter (site and situation of the place, proximity) as well as the social fabric of the place" (Cutter et al. 2003:243). Interaction between the social fabric and the biophysical location creates outcome vulnerability (Cutter et al. 2003:243). In this dissertation, place-based vulnerability plays a role in research into risk factor changes (Boeckmann & Joyner 2014), and in the case study on evaluation on the ground (Boeckmann 2015a). Overall, the concept also links to the place as a mediator of inequity and structural disadvantages, another aspect important for context in adaptation evaluation.

3.3 Vulnerability theories

At first glance vulnerability seems easy to understand: Vulnerability describes circumstances putting one at risk. If we look more closely, we are challenged with the inherent vastness of the concept of vulnerability. Diverse disciplines claim the term as their own and embed their unique connotations into the term (Füssel & Klein 2006; Adger 2006; Cutter 1996). The variety of histories and definitions require a choice, and this choice is generally rooted in the discipline one operates in and in the research subject. For the climate change and health research communities this means trying to bridge at least two disciplines: Public Health and environmental sciences. The latter again has a diverse portfolio and in climate change discourses borrows as much from human geography (social vulnerability) as from evolutionary biology (biological acclimatization) (Gallopín 2006).

The IPCC defines vulnerability as the "propensity or predisposition to be adversely affected" (IPCC 2014b:5). IPCC differentiates between outcome vulnerability and contextual vulnerability, acknowledging that "[v]ulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt," (IPCC 2014b:5). Ebi et al. (2006) define vulnerability in climate change as a function of sensitivity to changes, population characteristics, exposure, and adaptation.

3.3.1 The concept of vulnerability in Public Health

Judith Butler (2008) argues that any human body is inherently vulnerable, that we all share a "fundamental corporeal vulnerability." The term's etymology links back to the Latin terms "vulnus", "vulnerabilis" and "vulnerare:" "wound," "to be wounded," and "to wound," respectively (Fekete 2010:15; Chavez Rodriguez 2013:36). Humans are prone to get ill, to suffer, to die. Bodies and minds are at once fragile and able to withstand extreme shocks. Humans navigate constant health threats, and the goal of Public Health is to increase chances of not suffering (yet). In climate change research, not only people are vulnerable but the environment is shaped by climatic impacts as

well. In post-humanist thought, human and non-human actants shape the world (Rock et al. 2013). In this dissertation, two such non-human actants occur: a) climate change as a cause, and b) the environments to be adapted. Since both influence human health in return (Prüss-Üstün & Corvalán 2006), climate change research is thus a site of engagement for Public Health researchers.

Public Health interventions target risk factors to either prevent future occurrences of injury or illness as primary prevention, or to prevent further complications of existing conditions in secondary prevention. This premise echoes the problem of adaptation outlined in the background chapter: success is the absence of an adverse event. To establish failure or success of an intervention project, this absence has to be measured. Medical scientists work with proxy indicators: inconspicuous blood work, prevalence of pre-cancerous cells, or blood pressure among a "normal" spectrum all represent the absence of the disease in question. Vulnerability research also requires the use of a proxy to determine who might be more likely to suffer should an adverse event occur. Health-related examples of these proxies are usually mortality concepts such as specific hazard-related mortality or all-cause mortality. In climate change and health research specifically, definitions of the IPCC are in use, and discipline-specific theories of vulnerability to climate change do not exist. Instead, theories and definitions from other disciplines are appropriated and applied to the health context. This dissertation draws from human geography in its focus on place-based vulnerability. The following section presents a brief history of vulnerability theories in environment and human health.

3.3.2 Origins: a history of vulnerability theories in human – environment research

Disciplines engaging with the concept of vulnerability range from human geography, disaster risk research, ecology, and economics to sociology, psychology, engineering, and human health (Adger 2006). Indeed, Adger (2006) argues that only when looking at human-environment interaction can we even speak of a similar understanding of vulnerability across disciplines. The reason, Adger (2006) writes, lies in the importance

of a social-ecological systems approach to the concept of vulnerability. This makes sense as climate change acts on the physical environment but these physical environments are not ends to themselves. They in turn influence social interactions and human-made networks and environments.

Within climate change research, human – environment interactions are characterized by both social and ecological research traditions. Human power manipulates the environment, for example through pollution and greenhouse gas (GHG) emissions. As a result of climate change, natural hazard effects of this anthropogenic manipulation can become threats to human health. And finally, in response to these threats, humans manipulate environments again through climate change adaptation. This is an important consideration for vulnerability research: We are confronted with both the socially constructed vulnerability and the factual natural hazards. My definition of environment is linked with natural hazards research, and encompasses both human and non-human aspects.

Environments can be both natural and artificial, and both types matter when exploring and analyzing the effects of climate change. Bohle (2007) writes that three areas of investigation into the "geographies of vulnerability" are ecology, society and technology. The concept was thus developed in the environmental and social sciences (Bohle 2007). Wisner (2007) points out that at the center of what defines vulnerability to environmental hazards lies the awareness on how hazards' effects on humans are not "natural". Instead, deaths and destruction are rooted in current and historical "interdependencies of power, social and economic life, location, topography and ecology" (Wisner 2007:13, translated from German by MB).

Reflected in the variety of disciplines contributing to vulnerability research are the various origins of current vulnerability research developed in different disciplines. Researchers stress different traditions; what is considered to be the antecedent to

modern vulnerability research in the realm of the environment and climate change is contested. Among vulnerability theories, the concept of social vulnerability is of high relevance to human health. Adger (2006) points out two antecedent theories of social vulnerability he deems important:

1. Amartya Sen's theory of entitlements and
2. theories of vulnerability to natural hazards.

The second strand is divided again into the 'pressure-and-release' model, political ecology, and the probability and impact of natural hazards (Adger 2006:271).

3.3.2.1 Amartya Sen's theory of entitlements

Entitlements theory was developed by the economist Amartya Sen in 1977. Originally, Sen's work was based on theorizing famine in Sub-Saharan Africa (Chavez Rodriguez 2013; Kasperson et al. 2005). Sen aimed at explaining the reasons for famines through socio-economic causes and distinguished between *endowments*, goods or the ability to work, and *exchange entitlements*, the ability or opportunity to sell and exchange said goods and manpower (Chavez Rodriguez 2013; Kasperson et al. 2005). Where Sen included all rights and chances of a person to participate in goods exchanges it links to social vulnerability: the power to own and command goods that ensure access to food is not merely linked to natural events such as a good or poor harvest, but rather depends on the social structures distributing said power. The entitlements approach has been critiqued repeatedly in the past years specifically for its sole focus on market mechanisms (Chavez Rodriguez 2013; Gore 1993), and because it ignored physical or ecological impacts on food insecurity (Adger 2006). But Sen's influence on incorporation of economic and sociopolitical dependencies into hazards research and subsequently climate change research should not be underestimated (Adger 2006; Chavez Rodriguez 2013).

3.3.2.2 Natural hazards-based vulnerability

The role of natural hazards within ecological systems that Sen's theory of entitlements lacked lies at the heart of a second origin of vulnerability research: hazards-based vulnerability. Three influential research strands are discussed: Burton's concept of the environment as hazard, Hewitt's human ecology (Hewitt 1997), and the 'pressure-and-release' model (Wisner et al. 2004), a synthesis of the previous two.

Burton (1978) argues that how humans deal with an extreme event creates danger and therefore the hazard. His definition is closely linked to the social structures and constructed environments already discussed in place-based vulnerability as well. Burton writes about seven dimensions of a hazard that determine the hazardousness of an extreme event based on exceedance of a threshold (Burton 1978:22-23). These dimensions are magnitude, frequency, duration, areal extent, speed of onset, spatial dispersion, and temporal spacing (Burton 1978:22-23). Burton's dimensions allow both slow and fast onset extreme weather events to be viewed as hazards. Burton also coined the term "pervasive hazard" for heat, as cited in the background chapter (Burton 1978). Of interest to vulnerability research is Burton's view that human involvement and preparedness determine the extent of adverse effects. Further important aspects of Burton's framework are his links to responses to hazards, namely adaptation, and his inclusion of spatial vulnerability.

More specific than Burton, Hewitt stresses the increased vulnerability of poorer and marginalized groups in his book "Regions of Risk" (Hewitt 1997). Hewitt calls this a "human ecology of endangerment", and links it to location (Hewitt 1997:143; Adger 2006). Location matters as lower income households tend to cluster in areas most at risk from flooding, for example. Applied to the topic of heat and health, a similar phenomenon is the clustering of poorer households in densely populated, highly urbanized inner cities (see also Klinenberg 1999 for a more detailed discussion on the urban poor and disaster risks).

Drawing from previous approaches, the pressure and release model connects a hazard, also called pressure, on one hand, and a progression of vulnerability on the other (Wisner et al. 2004). Pressures of vulnerability comprise three aspects: root causes, dynamic pressures and unsafe conditions (Wisner et al. 2004). In this model, root causes of vulnerability are based on ideologies and power structures facilitating or preventing access. Dynamic pressures at the macro level may include rapid urbanization and population growth, but also freedom of press. Finally, the physical and social local environments can lead to unsafe conditions. A disaster occurs where the socio-economic pressures and the natural hazard intersect (Wisner et al. 2004). Risk of adverse effects is a result of hazard multiplied by vulnerability (Wisner et al., 2004).

All three natural hazards based vulnerability theories stress the social component that turns an extreme event into a risk or hazard. In this regard they relate to Sen's entitlements theory. In addition, their focus on a social dimension more adequately captures what makes a dangerous situation: the hazard interacts with the conditions and social fabrics "on the ground" with humans at the exposed center.

3.4 Criticisms of the social vulnerability concept

Despite its popularity and potential as an explanatory framework, even in spite of its continuous factual use in the climate change research community, vulnerability as a theory has its shortcomings. A major drawback is the conceptual variety collected under the term. Vulnerability can be viewed as an outcome or a context (O'Brien et al. 2004; O'Brien et al. 2007). Separating the two is challenging work. Possibly as a result, published research is not always explicit about these entanglements (O'Brien et al. 2004). Additionally, as stated before, the sheer number of disciplines adding to the canon of vulnerability definitions makes it difficult to operate from a shared viewpoint. Climate change and health research as a multidisciplinary endeavor requires careful consideration of the most appropriate concept to be used in studies. Using the IPCC definition as the authoritative voice can be helpful; but this very broad definition might also mean trying to grasp too many aspects at once. Yet another criticism states that all

current vulnerability approaches fail to include perception and "social construction of vulnerability" (Christmann & Ibert 2012). At this point, using established vulnerability theories from disaster risk and environmental health research to assess climate change adaptation is a viable and useful option. With more knowledge generated about the global issue of climate change, possibly new variations of vulnerability will be defined and applied.

The roles of gender and intersectionality in vulnerability are still rarely discussed in climate change and health projects. Most prominently, such considerations occur in research on lower income nations and disaster risks (Preet et al. 2010; World Health Organization 2011; Kukarenko 2011; Chavez Rodriguez 2013; European Institute for Gender Equality 2012; Skinner 2011; Kakota et al. 2011). Strengthening the gender perspective in future climate change research, also for high income research settings, could help better understand vulnerability risk factors and dynamics, and contribute to better adaptation concepts.

3.5 Social justice as a normative research framework

Adaptation research operates within a normative framework: climate change is seen as reality; and adaptation is viewed as desirable to prevent adverse effects of these changes. The knowledge gap on effectiveness implies an ethical dilemma: adaptation projects are implemented, yet whether these work or if they might lead to co-harms is not known. "Wait and see" is not an option, however, as adaptation needs to be implemented in the present to adjust systems for inevitable climatic impacts of the future. A core value of Public Health is the advancement of social justice (Gostin & Powers 2006), a normative viewpoint this dissertation shares. Climate justice is one aspect of this broader concept (Sovacool 2013). Within this research project, evaluation of adaptation is seen as a necessary effort to establish the use of strategies and measures in promoting the public's health under increased pressure from climatic changes.

4 Knee-deep in data? Reflections on data collection and analysis methods

This dissertation is designed as a mixed methods study, and consists of both quantitative and qualitative research. Overall, I approached my research topic through the following five sub-projects:

Quantitative approach:

- A quantitative modeling of vector niches,
- systematic review of heat adaptation effectiveness.

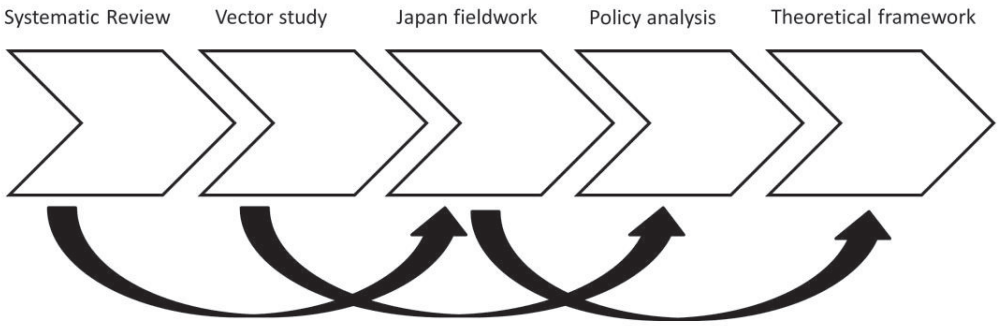
Qualitative approach:

- Critical policy analysis with discourse analysis,
- situational analysis of a case study: Semi-structured expert interviews, observation, and document analysis,
- theory-based framework on including climate justice in adaptation evaluation (presented in the results and discussion section).

This project placed equal emphasis on each approach to enable a thorough conceptual re-thinking of evaluation. Mixed methods are useful when working with complex research problems (Kelle 2008; Saks 2007; Silverman 2011). This multi-study design offered the opportunity to navigate the diversity inherent in climate change and health research. The systematic review attempts to answer research question a) on effectiveness of adaptation by using the example of heat and mortality and morbidity. The remaining four studies explore research question b) on how adaptation evaluation could be approached.

Within this project the research process was linear while allowing for feedback loops and circular elements. Results from each study informed additional analyses. A simplified overview over the research process can be illustrated as follows:

Figure 4: ***The research process***



The dissertation project was influenced by a constructivist point of view (Silverman 2011; Okely 2012). Constructivism acknowledges the "multiple meanings that people attach to what they do" (Silverman 2011:191). Additionally, the position assumes that realities are socially shaped by actors, interactions and institutions (Flick 2010). Arguing for the role of context necessitates a constructivist approach to socially shaped situations.

The choice of study regions, European countries and Japan, was driven mainly by these countries' principal capabilities to implement adaptation, and by their vulnerabilities to climatic changes (Box 2).

Box 2: ***Reasons for study region selection***

A) European countries and Japan have both financial and institutional capacities for adaptation combined with a history of environmental and Public Health policy (Imura & Schreurs 2005; Schreurs & Tiberghien 2007; Busse & Blümel 2014; Tatara & Okamoto 2009).

B) Highly urbanized areas in temperate regions are at great risk for adverse heat effects (Armstrong et al. 2011; Patz et al. 2005).

C) Climate justice is an issue at both global and local levels, also within higher income nations (Klein Rosenthal et al. 2014; Shonkoff et al. 2011; Bulkeley et al. 2014; Gardiner & Hartzell-Nichols 2012).

4.1 Tackling the problem of evaluation

The following paragraphs describe the specific methods employed in each part of the dissertation research. Starting from assessing the evidence base for adaptation effectiveness with a systematic review, evaluation is discussed as monitoring of risk factor changes, evaluating adaptation policy, and finally as evaluation on the ground. The final sections in this chapter cover triangulation and research ethics.

4.1.1 Evaluating the evidence base: systematic review methods

How effective is adaptation to heat? How have others dealt with the problem of evaluating adaptation, using heat as an example? We conducted a systematic literature review with focus on peer-reviewed publications. The review was published in BMC Public Health, and further details about the search methods can be found in the article (Boeckmann & Rohn 2014).

The following outcomes were of interest:

1. Reduction in heat-related morbidity and mortality.
2. Reduction in heat island exposure.

Article search and selection were guided by PRISMA guidelines. We conducted the searches in the databases PubMed, Web of Knowledge, Biological Abstracts, CAB Abstracts, and ProQuest Dissertations & Theses A&I, excluding articles without an English abstract, without actual evaluation, and non-research articles. We used the CASP checklists (Critical Appraisal Skills Programme (CASP) 2013) to assess study quality. Data synthesis was achieved through a narrative approach, as study heterogeneity prevented us from conducting a meta-analysis. We examined two subgroups of articles: those assessing morbidity and mortality changes through regression analysis, and those assessing changes in risk perception and behavior. Overall, 30 articles were included in the assessment.

Author's contribution: I conceptualized and designed the study, conducted the literature search, study quality appraisal and data analysis, and drafted the article.

4.1.2 Evaluating risk factor changes: the example of vector distribution changes under climate change

Heat not only influences temperature-related morbidity and mortality, but also plays a role in infectious disease vector lifecycle and distribution. *Ixodes ricinus* ticks, common tick-borne encephalitis vectors in Europe, are susceptible to environmental changes and depend on habitats with a suitable temperature and precipitation profile (Gern 2005). Thus climate change may alter distribution and abundance of ticks in Europe, as other studies have suggested (Feria-Arroyo et al. 2014). Risk factor changes are therefore a real possibility and will influence adaptation decision-making. T. Andrew Joyner and I conducted a health geography study on current and future suitable niches for *I.ricinus* ticks in Europe. Potential future tick habitats under an A2 climate scenario were modeled using a Genetic Algorithm for Rule-set Prediction (GARP) approach. GARP is open access software that models presence-only locality data, and analyzes the relationship between these data and environmental parameters in a specific location through an iterative training and testing process (Stockwell & Peters 1999).

The data set comprised 904 geo-referenced, spatially unique tick presence localities in Europe made accessible by the Global Biodiversity Information Facility (2013). Current climate-sensitive tick distribution was modeled for a baseline climate constructed from climate data averages from 1990–2010. To model future climatically suitable niches, we employed the CSIRO SRES A2 emissions scenario for the time period 2040–2060. The A2 is a high emissions scenario and assumes continued population growth and regionally fragmented economic growth (Consultative Group on International Agricultural Research (CGIAR) 2013). Climatic variables (often called bioclimatic variables) included in the model were annual mean solar radiation, iso-thermality, annual total precipitation, precipitation of wettest quarter, and precipitation of driest quarter at a resolution of 8km. Core bioclimatic variables (all variables used except solar radiation) were developed by Hijmans et al. (2005) and accessed from WorldClim. Solar radiation was calculated based on the methodology proposed by Kriticos et al. (2012).

Based on the climatic variables and current potential distribution, the GARP model proposed a future potential distribution map that we additionally tested for model agreement.

Further details about our methods can be found in the article (Boeckmann & Joyner 2014).

Author's contribution: I designed the study, conducted the literature search, applied the results to adaptation, and wrote the manuscript.

4.1.3 Evaluating adaptation policy: critical policy and discourse analysis methods

To assess whether European climate change adaptation can contribute to health protection, I conducted a document analysis with critical discourse analysis of 21 European national climate change adaptation strategies from 19 countries in close collaboration with my advisor. How well do these strategies take health impacts into account? We analyzed the documents from a social justice framework perspective, in line with this dissertation's theoretical background. Following the thematic

identification of health impacts and climate change adaptation approaches outlined in the strategy documents, we applied elements of critical discourse analysis to a subsample of six strategies from Austria, England, Finland, Greece, Sweden, and Wales.

Our assessment (Boeckmann & Zeeb 2014) is based on methods for critical discourse analysis outlined by Fairclough & Fairclough (2012) and Teun van Dijk (2002). In the strategy texts, *topics* and *values* related to social justice and health protection in climate change adaptation were identified and strategy documents ranked based on three main criteria: inclusion of social justice, social determinants and structural adaptation. The ranking formula was as such: each adaptation type included in a strategy was assigned one point for the partial score, on the basis that more comprehensive strategies with different types of adaptation measures carry greater potential to protect health. As weighting mechanisms we subsequently added percentage points to the partial score: 25% of the partial score for explicit mention of social justice or fairness, 20% of the partial score for addressing migration or demographic changes, and 15% of the partial score for inclusion of structural adaptation. The scoring system was inspired by Bittner et al. (2013) and the different weighting scores chosen to illustrate the assigned importance of each variable.

Author's contribution: I designed the study, chose the methods, analyzed the strategies, conducted the discourse analysis, devised the ranking approach, and wrote up the results.

4.1.4 Evaluating on the ground: a Japanese case study and situational analysis

This exploratory embedded single-case study examined heat adaptation within a local Japanese context. The goal was to map the context of heat adaptation evaluation "on the ground." Qualitative case studies have been proposed as useful designs for the study of „a contemporary phenomenon" that shall be "investigate[d] […] in depth and within its real-life context" (Yin, 2009:18). Climate change and adaptation are complex

contemporary phenomena that were investigated here through experts' perceptions and relevant discourses. Context of the case study was captured through the use of:

- ➔ Interviews with experts in 3 Japanese prefectures
- ➔ Observation
- ➔ Supporting documents
- ➔ Background reading

Collected data were analyzed based on Adele Clarke's situational analysis methodology (2005).

4.1.4.1 Data collection

Exploratory expert interviews

Interviewing took place in Japan during the summer of 2013, followed by analysis in winter 2014. As research into adaptation evaluation is still a new field and under-researched, study design was only semi-standardized to allow for new discoveries. Expert sampling was purposive. The exploratory interview phase in Japan was characterized by restrictions placed on the research: strict gatekeeping and limited access to experts representing institutions and governments required me to rely on Japanese colleagues for introductions. While I was able to communicate my research interests, I was not able to be in complete control over sample choice. This shortcoming was ameliorated by complementing generated interview data with observation memos.

A semi-structured interview guide was designed and translated into Japanese by Japanese researchers. To account for foci of experts' work and to elicit further information, deviation from the interview guide during the interviews was permitted where appropriate. Four interviews with eight respondents were conducted face to face in the experts' offices, with interpreters in Japanese and English on two occasions, in Japanese and German on one occasion, and completely in English without interpreter on one occasion (Boeckmann 2015a). The interviews were audio-recorded, and notes were taken and reworked into memos shortly after each interview.

The Japanese interviews were transcribed and subsequently translated into German by Japanese native speakers. I transcribed the English interview. All interviewees were provided with the questions before the interview. The interview transcripts were coded and used in the situational analysis.

Preliminary data analysis: coding

Prior to the situational analysis, I coded the interview transcripts openly based on adapted guidelines by Charmaz (2006). These data-driven codes were then refined and abstracted (focused coding), and after each coding round written into a new version of the codebook. Finally, the coded material was used in the situational analysis. Materials can be found in the article manuscript (Boeckmann 2015a) and in the appendix.

Observation

During my research visit to Japan I was invited to a local adaptation forum, a meeting of local governmental employees to discuss adaptation projects in their cities and regions. With the help of an interpreter I observed the discussions and collected print materials on local adaptation.

Cross-cultural research issues

Having to rely on interpreters and translated transcripts posed a challenge. Translation in cross-cultural research has been identified as a "co-construction of meaning" (Palmary 2011) that needs to be reflected by the researcher (Temple & Young 2004). As my research questions focused on concrete actions, interviewees were likely able to convey their practices without too much of it "lost in translation". My visible status as an outsider, a non-Japanese female researcher, can be expected to have had an influence on the interview situation as well. These issues are reflected in more detail in the article (Boeckmann 2015a).

4.1.4.2 Analysis methodology: situational analysis

Adele Clark (Clarke 2005) developed situational analysis in response to traditional grounded theory. The approach suited this project, as in contrast to grounded theory methodology in the traditional sense (Corbin & Strauss 2008), Clarke acknowledges that a complete "openness" towards the subject without having any theoretical knowledge or preconceptions is no longer possible. Situational analysis allows for prior knowledge as long as the researcher remains open to discovering unexpected findings throughout the research process (Clarke 2005). The methodology is based on conceptualizing *situations*. In principle, this means that a situation in itself is the unit of analysis. In this dissertation such a situation is heat and climate change adaptation in selected local Japanese governmental agencies. Clarke introduces the concept of relationality by exploring the position of something or someone in relation to other situations, sites, and actions (Clarke 2005:41). Applied to adaptation effectiveness research, relationality is useful because locality and places matter; the place in relation to the climate, a hazard, or an exposure creates risk; and adaptation targets a specific situation or a place.

At the heart of the situational analysis lie three approaches: situational maps, social worlds maps, and positional maps (Clarke 2005:xxii). Situational maps as the first analysis step describe the elements and their relations in the situation of interest. In a second step, social world maps articulate the collective concepts and discourses in which the situation occurs. And finally, positional maps draw attention to implicit and explicit positions taken in the relevant discourse (Clarke 2005:86).

Situational mapping

Situational maps

I first developed unstructured, then ordered situational maps from the coded interview data. Questions driving the mapping (Clarke 2005:87) were

- ➔ Who and what occurred in the situation?
- ➔ Who and what matters in the adaptation evaluation situation?

Choice of aspects to map was based on the research question and the categories identified through coding.

Social world maps

Based on my situational maps, I identified the social worlds within which the situation's actors (both human and nonhuman) operate. These social worlds were then ordered by assigning each previously identified actor to one or more worlds. Memos about the sites or places of these worlds accompanied the mapping.

Positional maps

Finally, several positional maps were developed, outlining where specific actors are positioned in a discourse. Discourses were based on the ordered situational maps and the discursive constructs thus identified.

4.2 Connecting the dots: triangulation

"Between-method triangulation" (Flick 2011), comparing data from documents gathered during the research visit to Japan and the interview data, was employed to identify conflicts in interpretation of the data. In addition, between-method triangulation is described as an opportunity to overcome individual methods' shortcomings (Denzin 1970). A second triangulation took place within the overall dissertation through synthesis of quantitative data (Boeckmann & Joyner 2014) and qualitative data (Boeckmann & Zeeb 2014; Boeckmann 2015a) in the discussion.

4.3 Research ethics

Direct human participation was limited to expert interviews on non-sensitive information. For the systematic review, discourse analysis, theoretical framework development and vector distribution studies, neither humans nor animals were directly involved in the research. For the Japanese exploratory expert interviews, oral consent for audio recording and interviewing was requested prior to beginning the interviews.

Interviewees were assured their names would neither appear in the dissertation nor in any publications resulting from this research. Participants were verbally assured their participation was voluntary, could be stopped at any time without any negative consequences, and no sensitive personal information was requested. In the write-up of the research, pseudonyms for locations and interviewees were used.

5 Results: approaches to adaptation evaluation

How can adaptation be evaluated? Do adaptation strategies have the potential to protect human health? How should we deal with the problems of establishing causal links between global climate change and human health? To illustrate the multimethod approach to these research questions, this chapter is divided according to the arena evaluation targets.

First, the results of our systematic review on heat adaptation effectiveness are presented. Evaluating risk factor changes in the vector distribution projection study is followed by evaluating adaptation policy through critical policy analysis. Evaluating in practice is discussed in the situational analysis results. Finally, the problem of evaluation is theorized in the theoretical framework for evaluation.

5.1 The state of things: effectiveness review results

Exemplary for one Public Health risk from climate change, our systematic review assessed the evidence base for effectiveness of heat adaptation (Boeckmann & Rohn 2014). The structured search procedure outlined in the methods chapter led to 30 included articles; the majority with observational study design (n=16). Additional study designs were quantitative surveys (n=6), qualitative interview studies (n=2), prior systematic reviews (n=4), one randomized control trial, and one economic analysis. Africa, Asia, South America and the Pacific region were underrepresented in the sample. Only publications from North America, Europe and East Asia could be included.

Overall, the studies reported a decline in sensitivity to heat over longer time periods, yet could not attribute the decline to any specific adaptation measure. Outcomes were diversely reported and difficult to combine and compare. For instance, studies reported mortality rates, excess deaths as counts, relative risks, odds ratios, mortality indices, or gave percentages of mortality increases or reduction.

Two themes emerged from the article review:
First, causality is the biggest problem in discussion on adaptation effectiveness. Clearly attributing long-term declines or changes after the implementation of adaptation was challenged by the lack of tested alternative hypotheses. Such hypotheses include biological adaptation, technological innovation, improvements to healthcare systems and access to care, adjustments to the urban built environment in urban planning, and societal developments. The role each of these aspects might play in the adaptation to heat is debated.

For the survey and interview studies focusing on behavior or risk perception, only one study included a pre-test. Without information on the prior knowledge of participants, no conclusive judgment can be made on the effectiveness of warning systems or warning messages.

And second, comparability between studies and subsequent statements on effectiveness were further hindered because of the following characteristics:

- heat waves differed in intensity and frequency, potentially mediating the impacts of each heat wave,
- confounders such as socio-economic variables and long-term healthcare improvements were not included in the analyses,
- in studies assessing a before and after period, the short time frame between implementation of heat prevention and subsequent evaluation may bias results,

- a heat prevention measure may consist of multiple interventions, causing simultaneous implementation and difficulty distinguishing between the effects of each, and
- limited data availability, also exemplified by the lack of pretests.

These results suggest that standard epidemiological research methods are currently unable to include all possible causal links between adaptation and health outcomes. Further methodological developments might be needed. Concurrently, normative considerations color the discussion about adaptation implementation: should we implement adaptation without knowing if and how it works? Could it be ill-advised to wait for conclusive research results, considering that extreme heat is already causing excess mortality? These questions relate to the policy implications of the review results.

Referring these results to the dissertation's theoretical foundations, vulnerability in these studies is expressed through the specified target group of older people. The examined studies acknowledged place-based risk profiles through mention of urban heat island effects. Yet, none of the studies employed a theoretical framework on how adaptation could influence these vulnerability factors. How adaptation options were chosen for specific locations was not inquired in the studies. All in all, the current state of effectiveness research is situated in observed changes and formulation of effectiveness hypotheses. Societal implications of theoretical assumptions about adaptation, health and evaluation problem links were not a subject of inquiry in the reviewed studies.

Results showed no conclusive answer to the first research question on effectiveness of adaptation, using heat adaptation as an example. The strong hints at declining sensitivity cannot be attributed directly to specific adaptation options. Thus the following studies explore research question two: how should we approach adaptation evaluation, and what could an alternative evaluation framework look like?

5.1.1 Outlook: strengthening time series studies through analysis of alternative hypotheses

The systematic review results show the difficulties associated with assessing the effects of adaptation on health through epidemiological study designs. To test a potential solution to these difficulties, in a collaborative research project conducted in the summer of 2013 the standard time series design was expanded to include the testing of alternative hypotheses (Boeckmann et al. 2015). Air conditioning prevalence was introduced as a possible alternative explanation for declining heat-related sensitivity (Bobb et al. 2014), and we additionally controlled for socioeconomic conditions at the prefectural level measured through average annual income, average savings, and Gini coefficients, as well as number of physicians per capita. Results showed an inverse risk relationship between cardiovascular mortality and air conditioning prevalence: prefectures with larger increases in air conditioning prevalence showed a smaller reduction in heat-related mortality during the examined summers. Similarly, prefectures with more physicians per capita presented lower reductions in heat-related summer mortality. These results suggest that neither air conditioning nor access to physicians can explain the long-term reductions in heat-related mortality in Japan.

An explicit analysis of alternative hypotheses in climate change related health research could help researchers better validate their time series results on morbidity and mortality developments under climate change. Such an approach could also ameliorate issues with establishing causality.

5.2 Evaluating risk factor changes: tick distribution modeling in Europe

Climate change adaptation aims at reducing risks and vulnerability to these risks. Current and future distribution of disease vectors is such a dynamic risk factor, assessed in our study on the impacts of rises in average temperature and risk of expanding suitable *Ixodes ricinus* tick habitats in Europe (Boeckmann & Joyner 2014). The GARP model estimated a current range of suitable habitats mostly in the northern regions of

Europe, in the United Kingdom, Ireland, the Netherlands, Belgium, and Denmark. Large areas of Sweden, Norway, Germany, and France also provide suitable habitats for *I. ricinus* ticks under the current climate. Less likely habitats (indicated through lower model agreement) were Spain, Italy, Austria, Croatia, the Czech Republic, Baltics, and Finland. In Southern Europe, high habitat suitability was modeled for mountainous regions such as the Alps of Switzerland, Austria, and northern Italy as well as the Pyrenees of northern Spain and southern France.

Results showed an overall expansion of potential *I. ricinus* habitats in Europe of 3.8%, from coverage of suitable niches of 24.2% of the modeled area to 28% of the modeled area under the A2 storyline. Consistently high possible concentration was projected for *already* high-risk areas for vector-borne disease contraction in Central Europe and the Southern regions of the Nordic countries were projected. Generally, risk factor changes will be strongly place-dependent: Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Belarus, and Denmark are expected to experience areas of expansion, whereas Croatia, Italy, France, Spain, and Germany are expected to experience areas of contraction.

Our study showed that adaptation to tick-borne diseases could focus on increased efforts to reduce current risks of vector-borne diseases. In this case, evaluating risk profile changes of a region within a short timeframe, as opposed to decade-long projects, might also prove useful. These results suggest that investing in improving current health systems and reducing existing risk environments of climate-sensitive diseases while simultaneously creating robust projections might be a feasible adaptation approach. If using open source software and data as we have done here, such a strategy could be applied in lower income contexts as well. This might also facilitate prioritization of adaptation in times of austerity.

5.3 Evaluating adaptation policy

In Boeckmann & Zeeb (2014), we assessed 21 European national adaptation strategy documents from 19 countries (three documents from the UK) and ranked these strategies against a social justice framework. Climate change impacts on health were recognized by all strategies, with heat and extreme weather events playing the largest role. Vector-borne diseases, food-borne diseases, or water-borne infections were mentioned in 86% of the documents, followed by changes in aeroallergen distribution and exacerbation of air pollution (57% each), an increase in UV radiation exposure (29%), mold development in houses (24%), food security (14%), and mental health issues (10%).

We defined four types of adaptation based on suggestions by Balbus et al. (1998):

1. Data and surveillance
2. Technological adaptation, including emergency plans and warning systems
3. Behavioral adaptation and awareness raising
4. Infrastructural adaptation.

Within the European documents, the most frequently recommended adaptation type was awareness raising and education programs (18 documents), followed by the technological adaptation and data/surveillance categories with 76% each. Infrastructural and engineering adaptation was mentioned in 14 documents. Germany, Denmark, Hungary, and Turkey advocate vaccine development for emerging infectious diseases. Health sector financing was proposed by Lithuania, and the Czech Republic suggested legislative changes at European and national level.

Ranked against the social justice and adaptation framework, Austria, England and Sweden received the highest scores with 6.4 points each. Six strategies ranked in second place, namely Belgium, Czech Republic, France, Germany, Norway, and Turkey. Wales ranked low with 2.9 points despite its commitment to social justice because the document suggested fewer adaptation types and excluded structural adaptation. Themes on values identified in the six subgroup documents from Finland, England,

Sweden, Wales, Greece and Austria showed that a) risks were perceived as contradictory, b) technology was viewed as savior, c) responsibilities needed to be negotiated, and d) social justice was advocated by only a few countries.

Our qualitative assessment showed that in European adaptation planning, progress could still be made through community involvement into adaptation decisions, consistent consideration of social and demographic determinants as well as a stronger link between infrastructural adaptation and the health sector. Additionally, the policy analysis also showed a political opportunity to target structural deficiencies: several strategy documents, including from Wales and Austria, expressed a desire to reduce social inequities, including gender inequities.

Regarding the research question, the policy analysis results suggest evaluating through a social justice framework as a useful tool. Acknowledging the social and cultural determinants of health that are additionally impacted by climate change, the approach aligns with the normative imperative of Public Health to protect health and strengthen social justice.

5.4 Exploring the health context: evaluating adaptation on the ground

Overall, the exploratory Japanese case study of local practices in three prefectures revealed discrepancies between the state of heat adaptation and the state of climate change adaptation more broadly. While heat adaptation is firmly established, these actions are not necessarily conceptualized as *climate change* adaptation. This makes an assessment of the actual measures implemented more difficult. Issues that arose during the interviews were challenges to adaptation from lack of funding and prioritization after the earthquake, tsunami and nuclear incident at Fukushima, and the responsibility for adaptation measures fragmented across departments and institutions. Evaluation of adaptation occurs irregularly and is perceived as scientifically challenging.

The state of heat adaptation at the local level is characterized by a strong focus on behavior change and awareness raising campaigns (I3:406; I2:556)[6] that include text message services (I1:1565), website downloads (I2:1061), print media and leaflets (I1:523; I3:38), but also local TV channel transmissions (I2:1644; I3: 330; I3:461). Vulnerability to adverse health effects of heat is discursively constructed to apply mainly to older persons, to a lesser extent also to construction workers and school children during physical education classes (I2:1328; I3:1994).

Structural adaptation through the provision of access to cooled public spaces was mentioned in two interviews in two prefectures (I3:58; I3:881; I2:1691), and incentives to increase green and white roofs of newly erected high-rise buildings were implemented in one of the three prefectures (I1:1490). Of high interest is the involvement of the civil society in adaptation efforts. Respondents mentioned volunteer social workers, *Minseii-in*, who visit older people at home during extreme heat events (I2:981; I2:577).

The situational analysis revealed that non-human actants and collective human actors outnumber individual actors: this embeddedness in a larger context beyond individuals' agencies could give valuable insights into how adaptation choices must be negotiated at the local level.

While a number of heat adaptation measures have been implemented, respondents admitted that funding was a major barrier to extensive prevention campaigns. In interview two, the interviewees described how they previously gave out cooling towels and "heat stroke measure items"[7] but had to cease doing so for lack of funding (I3:387, see also I2:547; I2:862 for discussion of budget). The 2011 Great East Japan Earthquake

[6] The given numbers refer to the start line of a coding as assigned by MaxQDA software and can be retrieved in the list of codings provided in the appendix.

[7] These heat stroke measure items combine thermometer and hygrometer: An alarm sounds if thermal conditions could lead to heat stress. They are for sale at popular Japanese chain stores such as *Tokyu Hands* or in electronics shops (I3: 585).

and Tsunami, together with political changes, play an important role in prioritization and risk perception, as one respondent described:

> *We got a very bad earthquake two years ago, and last year government changed. So when we started this project, […] atmosphere of the people is called forecast to climate change issue. But after earthquake [the] atmosphere is completely changed, and after governor change, so this [project] finished but our adaptation activity is stuck now (I1:168; see also I2:881).*

Hierarchies and communication channels are an additional challenge to adaptation, as a larger number of stakeholders might (re-)assign their responsibilities throughout the adaptation process (I1:771; I3:477; I4:673).

Finally, evaluation of adaptation measures was unanimously perceived as difficult and not a standard practice. For heat-related morbidity and mortality, ambulance transports of heat stroke patients and heat stroke deaths counts are the two main indicators used (I2:841; I3:311; I3:555). However, no feedback loops between information on developments of these indicators and (additional) adaptation activities were reported. Potentially useful could be a reporting system for green roofs on buildings (I1:955).
Further details on the issues discussed in the interviews and selected situational maps can be accessed in the article manuscript (Boeckmann 2015a).

5.5 An alternative evaluation option: reframing effectiveness

Results from the studies described above suggest that a number of methodological challenges associated with determining the effects of climate change adaptation on health. Our policy analysis revealed how applying a social justice framework can help evaluate adaptation policy. Taking this approach a step further, a theoretical framework for adaptation evaluation was developed that works with a proxy: instead of trying to assess the direct health outcomes of an adaptation measure, assessing the effects of adaptation on determinants of health through a set of seven domains is proposed (see

Boeckmann 2015b for illustration of the framework). The framework is not intended to replace empirical analysis, but rather to inform it.

Based on previous research into vulnerability (Cutter et al. 2014; Napier et al. 2014), the framework stresses the importance of broader social, cultural, and environmental determinants of health that are all affected by climate change, and in turn all affect health outcomes. Current adaptation research focuses on capturing the associations between adaptation and health outcomes directly. In light of the previously described black box of context, however, I argue that the complexity of climate change and the multiple paths between adaptation and health are better assessed through the proxy of contextual determinants of health. In addition, prioritizing changes to determinants that put health at risk regardless of climate change impacts can contribute to social justice, as these determinants are unequally distributed within populations and societies (Marmot et al. 2012).

The framework is intended to be used by researchers and policymakers. It can serve as a template for conceptualization of the associative paths between sectors, health determinants, and adaptation designs. Drawing from previous research into climate justice (Bulkeley et al. 2014) and into the importance of social aspects to Public Health (Marmot et al. 2012), the framework positions climate adaptation evaluation in a well-researched field, thus alleviating the difficulties arising from the novelty and complexity of climate change research.

The domains can be operationalized through choice of relevant indicators. Selected indicators to illustrate the seven domains are presented in (Boeckmann 2015b). As an additional strength of the framework the chosen domains allow users to set different foci. The roles of gender and diversity can thus also be included in the analysis, in line with the climate justice approach of this framework. As such, the framework is a useful concept to complement the empirical search for better evaluation methods and is an

example of what an alternative evaluation framework could resemble. Further research is needed to test this framework in evaluation of actual adaptation projects.

In answer to the research question, the framework suggests evaluating the role of adaptation in reduction of systemic disadvantages and situation-specific health risk determinants.

6 Discussion: in search of solutions to the evaluation problem

As stated in the background chapter, climate change adaptation has been described as a "wicked problem," referring to a systemic, imperfectly understood challenge without simple solutions (Feliciano & Berkhout 2013). The phenomenon's complexity and its context-specificity render it unsuitable for a "one size fits all" approach. Traditional epidemiological methods are currently unable to provide conclusive answers. A second challenge to evaluation of adaptation policy is its novelty and ambition: the same newly generated data are used simultaneously to learn more about climate change and to make decisions on mitigation and adaptation (Hansson 2012). This proves problematic, as the same process of generating scientific evidence is also used to generate practical applications, giving little room for error.

Despite these difficulties, this research project led to a better understanding of adaptation evaluation options. I conceptualized adaptation evaluation as a problem, highlighted what makes it a problem (Boeckmann & Rohn 2014; Boeckmann 2015a; Boeckmann 2015b), and suggested possible solutions (Boeckmann & Zeeb 2014; Boeckmann 2015a; Boeckmann 2015b; Boeckmann & Joyner 2014).

Based on these individual results, two overarching potential solution paths to the adaptation evaluation conundrum emerged: one methods-based solution and one theory-based. Following a discussion on strengths and challenges of the tools employed in this dissertation, I finally position my work in relation to further research needs and

policy implications.

6.1 A methods-based solution?

Two approaches are currently standard in epidemiological research on climate change: projecting future climate variables and expected impacts (World Health Organization 2014b), and conducting time series studies on historical data (Boeckmann & Rohn 2014). Early on in the research process, the systematic review showed that standard epidemiological methods to assess effectiveness reach limits with climate change and heat adaptation in particular. Reasons for this lie mainly with the absence of controls and the large number of confounding variables. As an outlook to other, possibly more useful study designs, I described a collaborative research project I conducted with Japanese researchers on long-term mortality and temperature developments in Japanese prefectures. In this project, air conditioning prevalence was tested as an alternative hypothesis for excess mortality reductions during extreme heat events. Including analyses of additional possible causes for morbidity or mortality in epidemiological climate change studies could help to increase validity of results, and subsequently increase our understanding of causal relationships between climate and human health. At this point, however, these approaches are not yet sufficiently developed or employed to be viewed as a standard.

Regarding projections of future climate change impacts on health, the assumptions underlying these projections need to be critically assessed. Specifically, the SSPs developed by IPCC researchers rely on a process of determining what is judged as likely and plausible. A different IPCC expert panel could have led to different assumptions of these SSPs. This need not be problematic if a reflective stance is taken towards both quantitative and qualitative projections: researchers need to be aware that even robust scenarios have limitations in accuracy, predictability, and relevance.

A third issue in climate change and health research methodology are the high standards

of what counts as effectiveness evidence in EBPH (Sackett et al. 1996). In the epidemiologic paradigm, the hierarchy of evidence begins with randomized controlled trials and ends with case study reports (Sackett et al. 1996). Yet these designs have difficulties capturing the black boxes of context that play a vital role in climate change adaptation. In general, the more complex an intervention, the less conducive it becomes to experiments (Abeysinghe & Parkhurst 2013). Rychetnik et al. (2002:119) describe evidence in Public Health research as the "interpretation of empirical data derived from formal research or systematic investigations, using any type of science or social science methods." Their definition is suited towards emerging problems and emerging methods to tackle these problems. In general, epidemiological evidence establishes "general or population-level causal links" (Broadbent, 2011a: 238); the field's methods are unable to prove *specific* causation. This holds true for all etiological knowledge derived from epidemiological studies (Rothman et al. 2008), and means that methods are unlikely or even unable to prove if an individual's illness is caused by a climatic influence (Broadbent 2011a).

6.1.1 Alternative methods for evaluation: learning from structural intervention approaches

How could alternative methods alleviate these three outlined challenges? My results propose to include policy analysis methods (described in Boeckmann & Zeeb 2014), to employ mixed methods approaches to map the context of adaptation, to analyze effects of adaptation on social, cultural, and environmental determinants of health as a proxy for direct health outcomes (described in Boeckmann 2015b), and to strengthen adaptation to current health risks, such as current infectious disease vector distribution (described in Boeckmann & Joyner 2014). When abstracted to an overarching formula, my findings suggest borrowing from the methods used in complex structural Public Health interventions.

6.1.1.1 Adaptation as complex prevention

Considering the overlap between health-related climate change adaptation and complex Public Health interventions (Datta & Petticrew 2013), tools borrowed from design and evaluation of structural prevention might be helpful. In contrast to programs focusing on individuals' behavior, structural Public Health interventions seek to alter the contextual and environmental factors that influence risk, risk behavior, and determinants of health (Blankenship et al. 2006). Such factors include social, economic, political, and physical environments (Blankenship et al. 2006). Referring back to place-based vulnerability and adaptation embedded in complex societal and environmental processes, such structural efforts could link determinants of adaptation to determinants of health. Drawing from unrelated policy interventions, such as food taxation (Thow et al. 2014), might be helpful.

Infrastructural and technological adaptation already rely more on environmental factors than individual behavioral change: using structural interventions tailored to the health effects of place-based vulnerability to climate change could further strengthen this approach. Similar to climate change adaptation, evaluation of structural interventions is often problematic as it must account for multiple pathways and determinants, long timeframes from implementation to visible outcomes, cross-sectoral actors, context, and complexity (Pronyk et al. 2013). Randomization as favored by evidence-based medicine and to some extent by Public Health is equally difficult in structural intervention and adaptation for ethical, political, and practical reasons (Pronyk et al. 2013). As a solution, application of mixed methods has been proposed, and various adjustments to existing evaluation methods have been suggested (Pronyk et al. 2013). Pronyk et al. (2013) give an overview of possible structural intervention evaluation methods. Among these, implementation research, qualitative approaches, and context mapping are of high interest as these are creative suggestions for a complex problem.

6.1.1.2 An evaluation method portfolio: implementation research, qualitative approaches, and context mapping

First, implementation research acknowledges the high degree of uncertainty about adaptation effects. Its exploratory approach allows evaluators to ask "how" rather than "if" an adaptation measure can protect human health. As previously argued in the background and theory chapters, the black box of context and the complex paths between climate change, adaptation, and health outcomes create the evaluation problem. Thus asking exploratory questions at this point is a feasible solution to tackling evaluation. While process evaluation is not a new suggestion for climate change adaptation (Ford et al. 2013; Wardekker et al. 2012; Dupuis & Biesbroek 2013), I propose focusing research methodology on understanding the paths between climate change impacts and the contextual environmental determinants of health, and on how adaptation can target specific factors creating place-based vulnerability. Knowledge generated could then be applied to additional evaluation designs.

Second, adding a qualitative component to the strong epidemiological tradition in climate and health outcomes research could help make sense of how changes in climate influence risk perception among policymakers and planners, and health behaviors among vulnerable populations. This requires a rethinking of the concept of effectiveness in Public Health as well, as discussed in further detail under theoretical solution paths: community efforts to amend structures or changed regulations might have to be considered as outcomes. One example worthy of further exploration are the Japanese volunteers (*Minseii-in*) visiting elderly people at home to reduce their risk of heat stress and heat stroke, as identified in the situational analysis results. How could such a cultural practice be evaluated as part of climate change adaptation evaluation? Involvement of civil society is currently not a variable generally included in the evaluation of health-related adaptation.

Finally, Pronyk et al.'s (2013) context mapping approach could be used to hypothesize

adaptation effects on human health and to select aspects for evaluation most likely related to vulnerability. The Japanese case study revealed how local context determines priorities and shapes adaptive response. Context mapping includes a wide range of tools from qualitative and quantitative research, such as stakeholder interviews, geographical mapping, document analyses, and observation (see Pronyk et al. 2013 for more examples). This method is useful for targeting one of the problematic aspects of adaptation evaluation, the contextual complexity, and might profit from being combined with complex intervention evaluation tools (Datta & Petticrew 2013).

6.1.2 Summary: useful methodological approaches to adaptation evaluation

The methods portfolio employed in this dissertation can be seen as both method and outcome. As an outcome, they show that a) tackling a complex problem such as adaptation evaluation requires multi-faceted tools, and b) for emerging problems, experimenting with methods is a valid approach.

Based on my findings, a number of approaches may strengthen our response to the evaluation problem. Suggested approaches include:

- Mixed methods approaches with strong qualitative components to capture complexity, from high quality projections to stakeholder elicitation.
- Assess feasibility of structural Public Health intervention tools for the design, implementation and evaluation of heat adaptation.
- Clearly define the context of the adaptation.
- Identify suitable controls to use as counterfactuals in study design.
- Always analyze alternative hypotheses for climate-related health impacts.
- Focus on the current state of risk and vulnerability.
- Apply theoretical frameworks to adaptation design and evaluation.

Additional considerations:

- The role of risk perception among stakeholders.

- Learning from natural experiments as methodology (Dinshaw et al. 2014; Banerjee & Duflo 2011).

The results of this dissertation suggest adding a stronger qualitative component to Public Health and climate change research. If using mixed methods, making the qualitative methods not the add-on, but truly integrating the two and giving them equal weight is of high importance. Context mapping seems particularly promising to capture the realities of places, climatic risks, and adaptation. These qualitative approaches could be combined with a "theory of change" to gain a better understanding of how the mechanisms of adaptation might lead to effects (Dinshaw et al. 2014).

6.2 A solution beyond methods: health in all adaptation policies, and transformation towards a climate just, healthy society

Methods to assess adaptation are useful tools, yet choice of these tools should be driven by a solid theoretical understanding of how adaptation is expected to influence health outcomes. Theory-based frameworks can assist these choices. Currently, contextual factors in climate change adaptation and health are not comprehensively understood. While increasing our efforts in conceptualizing the multiple pathways that matter to context and complexity of adaptation is mandatory, a normative approach to adaptation could be considered as well. This would entail a commitment to measuring and reducing inequities not only in policies, but also as integral part of evaluation.

6.2.1 Reframing effectiveness

One option to reframe adaptation evaluation is to reframe the concept of effectiveness in this specific context (Boeckmann 2015b). Instead of assessing direct impacts of adaptation on health outcomes, I propose using a proxy of adaptation impacts on social, cultural and environmental *determinants* of health. Such a framework can help circumnavigate the methodological challenges associated with identifying causal relationships between adaptation and specific outcomes. This framework additionally

strengthens awareness of the contexts adaptation is embedded in, which is less often included in evaluation designs. These contextual determinants of health inequity and injustice might be exacerbated by climate change. The new theoretical framework rethinks effectiveness as successful reduction of health risks and systemic disadvantages, in line with concepts of place-based vulnerability and social justice. Such an approach might be promising, as rights- based adaptation has previously been suggested (Ensor et al. 2015), but has not yet been explicitly connected to health.

6.2.2 Transformation

A second option might be to consider the risks and potentials of moving beyond incremental adaptation to both "health in all adaptation policies" and to transformational strategies (O'Brien 2011), and to put environmental and health justice at the center. Incremental adaptation describes add-ons to current practice without fundamentally rethinking goals of adaptation and its societal determinants (Kates et al. 2012). Applied to Public Health, transformational adaptation implies an alternative option: to seek opportunities to re-examine how Public Health is currently shaped by social, cultural, and environmental determinants, and to target broader structures rather than individual adaptation measures. Effectiveness in this design could also mean: effective at reducing current health inequities to minimize the risk of future exacerbation of these inequities. Such an approach is in line with experts' recommendation to strengthen current health systems as a prerequisite for successful adaptation (Smith et al. 2014; Bowen et al. 2014). In addition, targeting current place-based vulnerabilities could enable transformational public policy beyond the health sector. Transformation could be attempted by a "health in all adaptation policies" approach, drawing from experiences implementing the general health in all policies approach. Adaptation could equally be considered in health policies to stress the all-encompassing nature of climate and its risks, what one interview subject in the Japan case study called "adaptation mainstreaming" (Boeckmann 2015a). These conceptual frameworks focus on determinants of health rather than on outcomes. In the future,

both aspects are ideally combined in a "complete" framework that aims to both understand context and complexity, and to measure relevant effects of these determinants.

6.2.3 Health in all adaptation policies

In the European Union, "health in all policies" (HiAP) is already required for all EU policy (European Commission DG Health & Consumers 2014), and efforts to increase commitments at national (World Health Organization 2014a) and local levels (Corburn et al. 2014) are being made. Applying health in all adaptation policy *and* adaptation in all health policy could be a climate-smart move. Gostin & Powers (2006) indicate that Public Health is driven by two related ethical principles: "to advance human well-being by improving health and to do so by focusing on the needs of the most disadvantaged" (Gostin & Powers 2006:1054). Based on this premise, my theoretical framework for adaptation evaluation asserts that through alleviating current inequities, the subsequently ameliorated social, cultural, and environmental determinants of health can contribute to health protection under a changing climate. As such it might be a powerful interim solution until effectiveness of adaptation can be established with innovative methods. This approach is also linked to adaptation mainstreaming, as described in the Japanese interview study. Important actors tasked with improving evaluation methods and theories include the health sector, and environmental and urban planners, but also activists, civil society organizations, actors of the global policymaking sphere, and scientists working on interdisciplinary solutions. The proposed framework outlined cultural and social determinants of health as main aspects to link to climate change adaptation. Actors involved in any of the cultural, social, and environmental spheres play a role in health-focused adaptation as well.

Caveats to consider with this broad approach are potential adverse effects of Public Health interventions. While health co-benefits of climate mitigation strategies have been appraised (West et al. 2013; Thurston 2013; Haines et al. 2009), information on

possible risks of mitigation and adaptation remains scarce (Cheng & Berry 2013; Lorenc & Oliver 2014). An ethics appraisal of structural Public Health interventions and policies might be needed to estimate the risks of unwanted negative effects, as has also been proposed for "intervention-generated inequalities" (Lorenc et al. 2013). The term denotes the possibility that well-intended interventions may exacerbate inequalities between groups or individuals. This is particularly relevant in situations where the mechanisms of cause and effect are not yet fully explored, as is the case in climate change adaptation and health research. Additionally, the question of who is "allowed" to reframe the concept and measurements of effectiveness for what purpose needs to be considered as this flexibility could come at the expense of rigor and scientific integrity.

6.3 Contributions and limitations

6.3.1 Mixed methods and mixed philosophies

The individual empirical studies employed a number of theories from interdisciplinary backgrounds. These included climate change adaptation, public policy, human geography, philosophy of science, anthropology, and Public Health. Choosing appropriate contributions from each allowed me to better understand the complex problem of adaptation evaluation. At the same time, the pluralism of both methods and theories in this work meant sacrificing some specificity. I prioritized multiple perspectives on the problem of evaluation over an in-depth analysis of one approach. As climate change is a recent, "wicked" and contextually embedded health problem, exploration is warranted to recognize the shape and scope of climate change in Public Health research, and to pragmatically use "what works." A combined mixed methods approach with room for qualitative inquiry lends itself to the multifaceted philosophical *and* empirical questions the issue raises. Thus the methodological variety in this dissertation is both method *and* outcome.

6.3.2 Methodological contributions

This work explored evaluation through four different angles. The results of risk factor and policy evaluation, of exploratory case study, and of framework conceptualization all contribute to the solution portfolio outlined above. Three particularly interesting and useful methodological contributions resulted from this dissertation:

1) Assessing policy with a social justice framework and discourse analysis.
2) Exploratory case study including interviews, documents and observation.
3) Use of open source software and data for risk factor changes evaluation.

Public Health research into adaptation can profit from examining policy, as adaptation policy shapes the structures of health protection arenas. Critical policy appraisal methods can help widen the range of Public Health methods. The exploratory case study showed that various types of samples, such as interviews, document analysis, and ethnographic approaches are valuable contributions to a better understanding of reasons, perceptions, and contexts. Finally, using open source data and software makes this research replicable in lower income contexts, a contribution to a more equitable academic practice.

6.3.3 Theoretical contributions

This work's theoretical contributions include a new, theory-based adaptation evaluation framework, a strengthened link between climate justice and Public Health, and an additional definition of effectiveness as inequity reduction in the context of health and climate change adaptation. The theory-based framework on inequity-producing determinants of health and their role in assessing climate adaptation could be helpful as it does not require novel indicators. Instead, it focuses on known determinants. By combining cultural and social vulnerability domains with a transformational mandate, social justice could be promoted and vulnerabilities decreased.

My results stress the usefulness of a stronger commitment to include context and place in each adaptation assessment. The "adaptation paradox" (Ayers 2011) of this global problem with local impacts cannot be targeted without explicit analysis of the place in

individual evaluation projects.

6.3.4 Limitations

6.3.4.1 Limits to the methods

Several limitations need to be addressed. These are discussed in more detail in the individual article manuscripts. In brief, the following aspects need to be considered:

Qualitative interview study

The interview study focused on expert elicitation. Different interview partners could have led to different estimates of adaptation and evaluation priorities.

Additionally, the case study sample of interviewees, documents and observation memos was fairly small. Interview data were generated with the help of interpreters, external transcribers and translators: some aspects of the process were likely lost in translation. This is an issue in all transcultural research (Temple & Young 2004), and has been reflected thoroughly in the article together with issues of being a non-Japanese female researcher in a predominantly male work environment (Boeckmann 2015a).

Vector study

We projected future tick distribution based on one climate change scenario. Alternative scenarios could have presented a distinct risk profile for Europe. Similarly, a different dataset would have predicted different distribution patterns, as recent developments illustrate (Rubel et al. 2014; Estrada-Peña et al. 2014). Additionally, future models may consider different environmental variables as they relate to tick habitat suitability (Estrada-Peña et al. 2014).

Policy analysis

The policy analysis focused predominantly on Western and Northern European documents, as the data source lacked in full translated versions of strategies from most Eastern European countries. This may have biased the picture of adaptation planning in

Europe. However, bias is unlikely as the state of adaptation overall was at an early level, in these European strategies and in the Japanese sample. This early stage of implementation has also been reported for other countries (Austin et al. 2015; Lesnikowski et al. 2013).

Systematic review

The diverse study types included in the systematic review precluded a meta-analysis.

6.3.4.2 Limits to theory

The theoretical framework presented here has not yet been tested. Additionally, this framework is interdisciplinary in nature and not native to the discipline of Public Health. While this research only examined planned adaptation, biological adaptation could be an interesting phenomenon to study in the future. This work also broadly examined several climate impacts rather than a single one in depth, although heat and vector-borne infections played a major role.

6.4 Implications for further research

Several issues deserve further attention. First, the theoretical framework for justice and health-related adaptation evaluation could be compared and tested against different frameworks, such as the EBPH framework. A better understanding of alternative theories to explain the pathways between climate, adaptation, and health can support future adaptation design and evaluation.

Longitudinal studies on specific adaptation measures from inception to outcome and impact evaluation would be valuable but resource intensive. Consistent funding of research is necessary to allow such study designs in the field of climate change and health.

To better understand vulnerability to risks, directly involving people deemed at risk

through participatory designs is another possible future research project. Action research or participatory research studies would lend themselves to projects on health effects and climate justice. This could be particularly interesting within a multisite study to compare risk perception, behavioral change, and structural human - environment interaction. For instance, the Japanese case study could be repeated and enhanced in a different country, or expanded to more regions within Japan and complemented by a quantitative survey. Combined with rigorous context mapping, such an add-on to this research could contribute to new insights into the contextual determinants of adaptation decision-making and adaptation success.

Two additional research areas are of high interest for future projects. First, the role of sex and gender in climate change-related vulnerability has so far only been assessed in the context of extreme weather disasters. Broadening the field to examine how "doing gender" relates to climate change perception, environmental health outcomes, and processes of participation in adaptation could help create appropriate adaptation and evaluation. This is of particular relevance as gender has often been associated with higher risk profiles in lower income countries (Preet et al. 2010; World Health Organization 2011). Since the elderly have been classified as a vulnerable population, and a high percentage of older persons are female, a higher propensity for harm might occur regardless of location. Additionally, women earn less than their male-identified colleagues in higher income countries, too: income inequities influence social vulnerability. These factors all suggest a gender dimension to adaptation that might be relevant for evaluation. As not only gender and income, but also ethnicity, (dis)abilities, religion, and other aspects likely influence effectiveness of interventions, including intersectionality more deliberately into analyses could be useful. The theoretical framework paves the road for these variables through its diverse domains. Further research is necessary to explore hypotheses such as: will there be additional vulnerable groups not yet identified? Could adaptation itself lead to increased vulnerabilities? How will future interactions between populations and the environment shape health risks of

places?

Secondly, uncertainties associated with climate change continue to challenge researchers. The question need not necessarily be how to get rid of all uncertainties; this goal is far from being attainable. One alternative question could address how to deal with and how to understand the remaining uncertainties. Uncertainties could be quantified (Falloon et al. 2014; Wilby & Dessai 2010; Gosling et al. 2011), or coped with, pragmatically and less scientifically, through precaution, avoidance, or faith (Boholm 2003). Future research projects could assess the role each of these two strands: increasing knowledge about uncertainty, and how to practically deal with its presence in climate-related health behavior and outcomes.

6.5 Implications for future adaptation policy

Future adaptation policy could profit from application of theory-based adaptation frameworks. A clear hypothesis about the mechanisms between adaptation and health protection might increase success rates. Adding to these individual adaptation measures, as outlined it might be advisable to strengthen the "health in all adaptation policies" approach (Patrick et al. 2012). This should apply to all sectors, not only the health sector. Such an approach would be based on a precautionary principle and requires careful assessment of possible adverse effects of the adaptation measures themselves. If benefits of these measures are expected to exceed their potential negative effects, such a precautionary approach could contribute to health protection despite the previously mentioned uncertainties.

Most importantly, critical engagement with the role of social and climate justice within the health and adaptation nexus should be one task of future adaptation policy-making. Despite the challenges repeatedly discussed in this dissertation, these global changes do have an upside. They have started a discourse about societal transformation. As most adaptation efforts are new, they are still in a position to be shaped. Trans-sectoral

communication is necessary for adaptation regardless of political commitment: the opportunity to not only react to changes but also to proactively reduce current vulnerabilities to health risks could have positive effects on the health and well-being of both current and future populations.

6.6 The future of climate change adaptation research?

Overall, research into climate change and adaptation is central to a number of diverse disciplines. Strong frameworks such as the IPCC process, the international adaptation conferences, and WHO research on environment and health draw similar research interests together under the leadership of select senior researchers. The research community is small compared to other health research fields. One potential risk of this strong international leadership is a lack of giving space to contradictory voices: precisely because of the normative approach to climate mitigation and adaptation, critical research into adaptation itself is still rare and might be difficult to make public. So far, concerted efforts to include young researchers into the discussion have been lacking, but this seems to be changing. For instance, the adaptation network Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA)[8], supported by the United Nations Environmental Program (UNEP), plans to introduce a young researcher fellowship program.

Additionally, climate change and health offers a unique opportunity to proceed as the issue develops. Few research fields are as timely, international, and pressing as climate change and adaptation. A number of issues surrounding societal changes could be explored in the coming years.

[8] http://www.unep.org/provia/

7 Conclusions

My mixed methods study critically assessed options for climate change adaptation evaluation within Public Health. This dissertation posed the two core questions a) whether climate change adaptation is effectively protecting human health, and b) how to approach the "problem" of adaptation evaluation. In answer to the research question on effectiveness, I found inconclusive evidence for the effectiveness of heat adaptation for two reasons: first, the systematic review, policy analysis and case study showed that adaptation as a cross-sectoral project is not always putting health at the center. Second, the review additionally revealed how standard epidemiological methods struggle with attributing effects to specific, individual adaptation measures. These results informed the answers found to my second research question on how to re-think evaluation. I suggested a multimethod approach and developed a theoretical framework for the inclusion of justice into evaluation. My work contributes to the literature on climate change and health by adding a meta-theory level to health-related adaptation. This dissertation's results on effectiveness are in line with current knowledge on adaptation evaluation challenges (Bassil & Cole 2010; Bouzid et al. 2013). Applying climate justice and place-based vulnerability concepts to health-related adaptation evaluation suggests a new way of thinking about evaluation.

These findings could be of interest to both the health and environmental protection practice communities, as my results recommend social justice and societal transformation as benchmarks for climate change adaptation. Policymakers might benefit from considering a "health in all adaptation policies" approach that incorporates the precautionary principle of adapting now for possible future risks.

Further research ought to be conducted on alternative methods for adaptation assessment in Public Health. To better understand the role of contextual factors in health-focused climate change adaptation, context mapping could be a useful approach. My work suggests considering social, cultural and environmental determinants of health

from a social and climate justice perspective. Assessing the role for participatory research designs could prove beneficial.

8 References[9]

Abeysinghe, S. & Parkhurst, J., 2013. *"Good" evidence for improved policy making: from hierarchies to appropriateness*, London: London School of Hygiene and Tropical Medicine.

Abrahamson, V. et al., 2009. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. *Journal of Public Health (Oxford, England)*, 31(1), pp.119–126.

Adam-Poupart, A. et al., 2013. Climate change and Occupational Health and Safety in a temperate climate: potential impacts and research priorities in Quebec, Canada. *Industrial Health*, 51(1), pp.68–78.

Adger, W.N., 2006. Vulnerability. *Global Environmental Change*, 16(3), pp.268–281.

Ahern, M., Kovats, R.S., Wilkinson, P., Few, R. & Matthies, F., 2005. Global health impacts of floods: epidemiologic evidence. *Epidemiologic Reviews*, 27(1), pp.36–46.

Aida, J. et al., 2011. Assessing the association between all-cause mortality and multiple aspects of individual social capital among the older Japanese. *BMC Public Health*, 11, p.499.

Alberini, A., Gans, W. & Alhassan, M., 2011. Individual and public-program adaptation: coping with heat waves in five cities in Canada. *International Journal of Environmental Research and Public Health*, 8(12), pp.4679–4701.

Alston, M., 2010. Gender and climate change in Australia. *Journal of Sociology*, 47(1), pp.53–70.

America's Climate Choices: Panel on Adapting to the Impacts of Climate Change, Board on Atmospheric Sciences and Climate Studies, Division on Earth and Life & National Research Council, 2010. *Adapting to the ompacts of climate change*, Washington, D.C.: The National Academies Press.

Anderson, B.G. & Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology*, 20(2), pp.205–13.

Anderson, G.B., Dominici, F., Wang, Y., McCormack, M.C., Bell, M.L. & Peng, R.D., 2013. Heat-related emergency hospitalizations for respiratory diseases in the Medicare

[9] This reference list is limited to sources used in the dissertation text. For the reference lists relating to each of the five articles, please refer to the respective manuscripts.

population. *American Journal of Respiratory and Critical Care Medicine*, 187(10), pp.1098–103.

Armstrong, B. et al., 2011. Association of mortality with high temperatures in a temperate climate: England and Wales. *Journal of Epidemiology and Community Health*, 65(4), pp.340–5.

Armstrong, B., Gasparrini, A. & Hajat, S., 2014. Estimating mortality displacement during and after heat waves. *American Journal of Epidemiology*, 179(12), pp.1405–6.

Arnell, N.W. et al., 2013. A global assessment of the effects of climate policy on the impacts of climate change. *Nature Climate Change*, 3, pp.512–519.

Arnell, N.W. et al., 2004. Climate and socio-economic scenarios for global-scale climate change impacts assessments: characterising the SRES storylines. *Global Environmental Change*, 14, pp.3–20.

Arora-Jonsson, S., 2011. Virtue and vulnerability: Discourses on women, gender and climate change. *Global Environmental Change*, 21(2), pp.744–751.

Austin, S., Ford, J., Berrang-Ford, L., Araos, M., Parker, S. & Fleury, M., 2015. Public Health adaptation to climate change in Canadian jurisdictions. *International Journal of Environmental Research and Public Health*, 12(1), pp.623–651.

Ayers, J., 2011. Resolving the adaptation paradox: exploring the potential for deliberative adaptation policy-making in Bangladesh. *Global Environmental Politics*, 11(1), pp.62–88.

Ayers, J., 2010. *Understanding the adaptation paradox: can global climate change adaptation policy be locally inclusive?* London School of Economics and Political Science.

Azhar, G.S. et al., 2014. Heat-related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave. S. Akiba, ed. *PloS One*, 9(3), p.e91831.

Baccini, M. et al., 2011. Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios. *Journal of Epidemiology and Community Health*, 65(1), pp.64–70.

Bai, L., Morton, L.C. & Liu, Q., 2013. Climate change and mosquito-borne diseases in China: a review. *Globalization and Health*, 9, p.10.

Balbus, J.M., Bouma, M., Kovats, S., LeSueur, D., Martens, W.C. & Patz, J.A., 1998. Human health. In J. F. Feenstra et al., eds. *Handbook on methods for climate change impact assessment and adaptation strategies*. Nairobi und Amsterdam: United Nations Environment Programme (UNEP) und Vrije Universiteit Amsterdam, pp. 10–31.

Ballester, J., Robine, J.-M., Herrmann, F.R. & Rodó, X., 2011. Long-term projections and acclimatization scenarios of temperature-related mortality in Europe. *Nature Communications*, 2, p.358.

Banerjee, A. V & Duflo, E., 2011. *Poor economics: a radical rethinking of the way to fight global poverty* 1. ed., New York, NY: Public Affairs.

Banwell, C., Dixon, J., Bambrick, H., Edwards, F. & Kjellström, T., 2012. Socio-cultural reflections on heat in Australia with implications for health and climate change adaptation. *Global Health Action*, 5, p.19277.

Barnett, A.G., Hajat, S., Gasparrini, A. & Rocklöv, J., 2012. Cold and heat waves in the United States. *Environmental Research*, 112, pp.218–24.

Barrett, S., 2013. Local level climate justice? Adaptation finance and vulnerability reduction. *Global Environmental Change*, 23(6), pp.1819–1829.

Bassil, K.L. et al., 2011. The relationship between temperature and ambulance response calls for heat-related illness in Toronto, Ontario, 2005. *Journal of Epidemiology and Community Health*, 65(9), pp.829–31.

Bassil, K.L. & Cole, D.C., 2010. Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: a structured review. *International Journal of Environmental Research and Public Health*, 7(3), pp.991–1001.

Bauer, G.R., 2014. Incorporating intersectionality theory into population health research methodology: challenges and the potential to advance health equity. *Social Science & Medicine*, 110, pp.10–7.

Beggs, P.J., 2010. Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. *International Journal of Environmental Research and Public Health*, 7(8), pp.3006–3021.

Berrang-Ford, L., Ford, J.D. & Paterson, J., 2011. Are we adapting to climate change? *Global Environmental Change*, 21(1), pp.25–33.

Berry, H.L., 2009. Pearl in the oyster: climate change as a mental health opportunity. *Australasian Psychiatry: Bulletin of Royal Australian and New Zealand College of Psychiatrists*, 17(6), pp.453–456.

Berry, H.L., Bowen, K. & Kjellstrom, T., 2010. Climate change and mental health: a causal pathways framework. *International Journal of Public Health*, 55(2), pp.123–132.

Bi, P. et al., 2011. The effects of extreme heat on human mortality and morbidity in Australia: implications for public health. *Asia-Pacific Journal of Public Health*, 23(2 Suppl), p.27S–36.

Biagini, B., Bierbaum, R., Stults, M., Dobardzic, S. & McNeeley, S.M., 2014. A typology of adaptation actions: A global look at climate adaptation actions financed through the Global Environment Facility. *Global Environmental Change*, 25, pp.97–108.

Biesbroek, G.R. et al., 2010. Europe adapts to climate change: Comparing national adaptation strategies. *Global Environmental Change*, 20(3), pp.440–450.

Bittner, M.-I., Matthies, E.F., Dalbokova, D. & Menne, B., 2013. Are European countries prepared for the next big heat-wave? *European Journal of Public Health*, 24(4), pp.615–619.

Blankenship, K.M., Friedman, S.R., Dworkin, S. & Mantell, J.E., 2006. Structural interventions: concepts, challenges and opportunities for research. *Journal of Urban Health*, 83(1), pp.59–72.

Bobb, J.F., Peng, R.D., Bell, M.L. & Dominici, F., 2014. Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives*, 122(8), pp.811–816.

Boeckmann, M., 2015a. Exploring the health context: a qualitative study of local heat and climate change adaptation in Japan.

Boeckmann, M. et al., 2015. Heat-related mortality: effect modification and adaptation in Japan from 1972-2010.

Boeckmann, M., 2015b. Reframing effectiveness: climate change adaptation, human health, and the role of climate justice in evaluation.

Boeckmann, M. & Joyner, T.A., 2014. Old health risks in new places? An ecological niche model for I. ricinus tick distribution in Europe under a changing climate. *Health & Place*, 30C, pp.70–77.

Boeckmann, M. & Rohn, I., 2014. Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC Public Health*, 14(1), p.1112.

Boeckmann, M. & Zeeb, H., 2014. Using a social justice and health framework to assess European climate change adaptation strategies. *International Journal of Environmental Research and Public Health*, 11(12), pp.12389–12411.

Bohle, H.-G., 2007. Geographien von Verwundbarkeit [Geographies of vulnerability]. *Geographische Rundschau*, 59(10), pp.20–25.

Böhmelt, T., 2013. Civil society lobbying and countries' climate change policies: a matching approach. *Climate Policy*, 13(6), pp.698–717.

Boholm, Å., 2003. The cultural nature of risk: Can there be an anthropology of uncertainty? *Ethnos*, 68(2), pp.159–178.

Bolte, G., 2012. Environment-related inequalities. In World Health Organization, ed. *Environmental health inequalities in Europe. Assessment report*. Copenhagen: WHO Regional Office for Europe, pp. 86–113.

Borbora, J. & Das, A.K., 2014. Summertime urban deat island study for Guwahati City, India. *Sustainable Cities and Society*, 11, pp.61–66.

Bortz, J., 2006. *Forschungsmethoden und Evaluation: für Human- und Sozialwissenschaftler*, Heidelberg: Springer.

Bouchama, A., Dehbi, M., Mohamed, G., Matthies, F., Shoukri, M. & Menne, B., 2007. Prognostic factors in heat wave related deaths: a meta-analysis. *Archives of Internal Medicine*, 167(20), pp.2170–6.

Bouchama, A. & Knochel, J.P., 2002. Heat stroke. *The New England Journal of Medicine*, 346(25), pp.1978–88.

Bours, D., McGinn, C. & Pringle, P., 2013. *Monitoring & evaluation for climate change adaptation: A synthesis of tools , frameworks and approaches*, Phnom Penh and Oxford: SEA Change Community of Practice and UKCIP.

Bouzid, M., Hooper, L. & Hunter, P.R., 2013. The effectiveness of public health interventions to reduce the health impact of climate change: a systematic review of systematic reviews M. da Silva Nunes, ed. *PloS One*, 8(4), p.e62041.

Bowen, K.J., Ebi, K. & Friel, S., 2014. Climate change adaptation and mitigation: next steps for cross-sectoral action to protect global health. *Mitigation and Adaptation Strategies for Global Change*, 19(7), pp.1033–1040.

Boykoff, M.T., Frame, D. & Randalls, S., 2010. Discursive stability meets climate instability: A critical exploration of the concept of “climate stabilization” in contemporary climate policy. *Global Environmental Change*, 20(1), pp.53–64.

Broadbent, A., 2011a. Epidemiological evidence in proof of specific causation. *Legal Theory*, 17(04), pp.237–278.

Broadbent, A., 2011b. Inferring causation in epidemiology: mechanisms, black boxes, and contrasts. In P. I. McKay, F. Russo, & J. Williamson, eds. *Causality in the Sciences*. Oxford: Oxford Univ. Press, pp. 45–69.

Brooks, N., Anderson, S., Burton, I., Fisher, S., Rai, N. & Tellam, I., 2013. *An operational framework for Tracking Adaptation and Measuring Development (TAMD)*, London and Edinburgh: IIED Climate Change Working Paper No. 5.

Browning, C.R., Wallace, D., Feinberg, S.L. & Cagney, K.A., 2006. Neighborhood social processes, physical conditions, and disaster-related mortality: the case of the 1995 Chicago heat wave. *American Sociological Review*, 71(4), pp.661–678.

Bulkeley, H., Edwards, G.A.S. & Fuller, S., 2014. Contesting climate justice in the city: Examining politics and practice in urban climate change experiments. *Global Environmental Change*, 25, pp.31–40.

Burton, I., 1978. *The environment as hazard*, New York: Oxford Univ. Press.

Burton, I., Huq, S., Lim, B., Pilifosova, O. & Schipper, E.L., 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. *Climate Policy*, 2(2), pp.145–159.

Busse, R. & Blümel, M., 2014. Germany: health system review. *Health Systems in Transition*, 16(2), pp.1–296.

Butler, J., 2008. *Giving an account of oneself* 2nd ed., New York: Fordham University Press.

Campbell-Lendrum, D. & Corvalan, C., 2007. Climate change and developing-country cities: implications for environmental health and equity. *Journal of Urban Health*, 84(3 Suppl), pp.i109–17.

Campbell-Lendrum, D. & Woodruff, R., 2007. *Climate change. Quantifying the health impact at national and local levels* A. Pruess-Uestuen & C. Corvalan, eds., Geneva: World Health Organization.

Carbajo, A.E., Cardo, M. V & Vezzani, D., 2012. Is temperature the main cause of dengue rise in non- endemic countries? The case of Argentina. *International Journal of Health Geographics*, 11(1), p.26.

Carter, J.G., 2011. Climate change adaptation in European cities. *Current Opinion in Environmental Sustainability*, 3(3), pp.193–198.

Chang, C.-R., Li, M.-H. & Chang, S.-D., 2007. A preliminary study on the local cool-island intensity of Taipei city parks. *Landscape and Urban Planning*, 80(4), pp.386–395.

Charmaz, K., 2006. *Constructing grounded theory*, London [u.a.]: SAGE.

Chavez Rodriguez, L., 2013. *Klimawandel und Gender: Untersuchung der Bedeutung von Geschlecht für die soziale Vulnerabilität in überflutungsgefährdeten Gebieten*. Universität Bremen.

Cheng, J.J. & Berry, P., 2013. Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature. *International Journal of Public Health*, 58(2), pp.305–11.

Christenson, E., Elliott, M., Banerjee, O., Hamrick, L. & Bartram, J., 2014. Climate-related hazards: a method for global assessment of urban and rural population exposure to cyclones, droughts, and floods. *International Journal of Environmental Research and Public Health*, 11(2), pp.2169–2192.

Christmann, G.B., Heimann, T., Mahlkow, N. & Balgar, K., 2012. Klimawandel als soziale Konstruktion? *Zeitschrift für Zukunftsforschung*, 1 (2012), pp.20–36.

Christmann, G.B. & Ibert, O., 2012. Vulnerability and resilience in a socio-spatial perspective. *Raumforschung und Raumordnung*, 70(4), pp.259–272.

Chung, J.-Y., Honda, Y., Hong, Y.-C., Pan, X.-C., Guo, Y.-L. & Kim, H., 2009. Ambient temperature and mortality: An international study in four capital cities of East Asia. *Science of The Total Environment*, 408(2), pp.390–396.

Clarke, A.E., 2005. *Situational analysis*, Thousand Oaks, Calif. [u.a.]: Sage Publ.

Confalonieri, U. et al., 2007. Human health. In M. L. Parry et al., eds. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, pp. 391–431.

Consultative Group on International Agricultural Research (CGIAR), 2013. Research Program on Climate Change, Agriculture and Food Security. Available at: http://www.ccafs-climate.org/ [Accessed March 18, 2015].

Corbin, J.M. & Strauss, A.L., 2008. *Basics of qualitative research: techniques and procedures for developing grounded theory* 3rd ed., Los Angeles, Calif. [u.a.]: Sage Publ.

Corburn, J., Curl, S. & Arredondo, G., 2014. A health-in-all-policies approach addresses many of Richmond, California's place-based hazards, stressors. *Health Affairs*, 33(11), pp.1905–1913.

Crabtree, A., 2012. Climate change and mental health following flood disasters in developing countries, a review of the epidemiological literature: what do we know, what is being recommended? *Australasian Journal of Disaster and Trauma Studies*, 1, pp.21–30.

Critical Appraisal Skills Programme (CASP), 2013. Critical Appraisal Skills Programme: making sense of evidence. Available at: http://www.casp-uk.net [Accessed March 27, 2015].

Cummins, S., Curtis, S., Diez-Roux, A. V & Macintyre, S., 2007. Understanding and representing "place" in health research: a relational approach. *Social Science & Medicine*, 65(9), pp.1825–38.

Cutter, S.L., 1996. Vulnerability to environmental hazards. *Progress in Human Geography*, 20(4), pp.529–539.

Cutter, S.L., Ash, K.D. & Emrich, C.T., 2014. The geographies of community disaster resilience. *Global Environmental Change*, 29, pp.65–77.

Cutter, S.L., Boruff, B.J. & Shirley, W.L., 2003. Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2), pp.242–261.

D'Ippoliti, D. et al., 2010. The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environmental Health*, 9, p.37.

Das, S. & Smith, S.C., 2012. *Awareness as an adaptation strategy for reducing mortality from heat waves: evidence from a disaster risk management program in India*, Kathmandu: Sandee Working Paper No. 72-12.

Datta, J. & Petticrew, M., 2013. Challenges to evaluating complex interventions: a content analysis of published papers. *BMC Public Health*, 13(1), p.568.

Denzin, N.K., 1970. *The Research Act in Sociology*, Chicago: Aldine.

Dessai, S., 2002. Heat stress and mortality in Lisbon part I. Model construction and validation. *International Journal of Biometeorology*, 47(1), pp.6–12.

Dhiman, R.C., Pahwa, S., Dhillon, G.P.S. & Dash, A.P., 2010. Climate change and threat of vector-borne diseases in India: are we prepared? *Parasitology Research*, 106(4), pp.763–73.

Van Dijk, T., 2002. Multidisciplinary CDA: a plea for diversity. In R. Wodak & M. Meyer, eds. *Methods of critical discourse analysis*. London [u.a.]: Sage, pp. 95–120.

Dinshaw, A., Fisher, S., Mcgray, H., Rai, N. & Schaar, J., 2014. *Monitoring and evaluation of climate change adaptation. Methodological approaches*, Paris: OECD Environment Working Papers No. 74.

Dixon, P. et al., 2007. Effects of temperature variation on suicide in five U.S. counties, 1991–2001. *International Journal of Biometeorology*, 51(5), pp.395–403.

Donaldson, G.C., Keatinge, W.R. & Saunders, R.D., 2003. Cardiovascular responses to heat stress and their adverse consequences in healthy and vulnerable human populations. *International Journal of Hyperthermia*, 19(3), pp.225–35.

Van Drunen, M.A., van't Klooster, S.A. & Berkhout, F., 2011. Bounding the future: The use of scenarios in assessing climate change impacts. *Futures*, 43(4), pp.488–496.

Dupont, C., 2012. Gender and climate change: an introduction. *Global Environmental Politics*, 12(1), pp.128–129.

Dupuis, J. & Biesbroek, R., 2013. Comparing apples and oranges: The dependent variable problem in comparing and evaluating climate change adaptation policies. *Global Environmental Change*, 23(6), pp.1476–1487.

Ebi, K.L. et al., 2013. A new scenario framework for climate change research: background, process, and future directions. *Climatic Change*, 122(3), pp.363–372.

Ebi, K.L., 2009. Public health responses to the risks of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine*, 51(1), pp.4–12.

Ebi, K.L. & Burton, I., 2008. Identifying practical adaptation options: an approach to address climate change-related health risks. *Environmental Science & Policy*, 11(4), pp.359–369.

Ebi, K.L., Kovats, R.S. & Menne, B., 2006. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. *Environmental Health Perspectives*, 114(12), pp.1930–4.

Edenhofer, O. et al., 2014. Technical Summary. In O. Edenhofer et al., eds. *Climate Change 2014: Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press, pp. 33–107.

Ensor, J.E., Park, S.E., Hoddy, E.T. & Ratner, B.D., 2015. A rights-based perspective on adaptive capacity. *Global Environmental Change*, 31, pp.38–49.

Estrada-Peña, A., Estrada-Sánchez, A. & de la Fuente, J., 2014. A global set of Fourier-transformed remotely sensed covariates for the description of abiotic niche in epidemiological studies of tick vector species. *Parasites & Vectors*, 7(1), p.302.

European Center for Disease Prevention and Control, 2015. Ticks can carry disease. Available at: http://ecdc.europa.eu/en/healthtopics/emerging_and_vector-borne_diseases/tick_borne_diseases/key_messages/pages/key-messages.aspx [Accessed March 20, 2015].

European Commission DG Health & Consumers, 2014. Health in all policies. Available at: http://ec.europa.eu/health/health_policies/policy/index_en.htm [Accessed November 7, 2014].

European Evironment Agency (EEA), 2013. *Adaptation in Europe - Addressing risks and opportunities from climate change in the context of socio-economic developments.*, Copenhagen: European Environment Agency (EEA).

European Institute for Gender Equality, 2012. *Gender equality and climate change - Main findings*, Brussels: European Institute for Gender Equality. Available at: http://www.eige.europa.eu/sites/default/files/Gender Equality and Climate Change - Main Findings.pdf [Accessed March 20, 2015].

Fairclough, I. & Fairclough, N., 2012. *Political discourse analysis. A method for advanced students*, London [u.a.]: Routledge.

Falloon, P., Challinor, A., Dessai, S., Hoang, L., Johnson, J. & Koehler, A.-K., 2014. Ensembles and uncertainty in climate change impacts. *Frontiers in Environmental Science*, 2, p.33.

Fekete, A., 2010. *Assessment of social vulnerability to river floods in Germany*, Bonn: UNU-EHS Graduate Research Series Vol. 4.

Feliciano, D. & Berkhout, F., 2013. Dealing with “wicked” environmental problems. In *World Social Science Report 2013: Changing Global Environments*. Paris: International Social Science Council and UNESCO, pp. 415–419.

Feria-Arroyo, T.P. et al., 2014. Implications of climate change on the distribution of the tick vector Ixodes scapularis and risk for Lyme disease in the Texas-Mexico transboundary region. *Parasites & Vectors*, 7(1), p.199.

Flick, U., 2010. *Qualitative Sozialforschung - eine Einführung*, Reinbek bei Hamburg: Rowohlt.

Flick, U., 2011. *Triangulation* 3rd ed., Wiesbaden: VS Verlag für Sozialwissenschaften.

Ford, J.D. & Berrang-Ford, L., 2015. The 4Cs of adaptation tracking: consistency, comparability, comprehensiveness, coherency. *Mitigation and Adaptation Strategies for Global Change*, In press.

Ford, J.D., Berrang-Ford, L., Lesnikowski, A., Barrera, M. & Heymann, S.J., 2013. How to track adaptation to climate change: a typology of approaches for national-level application. *Ecology and Society*, 18(3), p.40.

Friel, S., 2010. Climate change, food insecurity and chronic diseases: sustainable and healthy policy opportunities for Australia. *New South Wales Public Health Bulletin*, 21(5-6), pp.129–133.

Friel, S., Hancock, T., Kjellstrom, T., McGranahan, G., Monge, P. & Roy, J., 2011. Urban health inequities and the added pressure of climate change: an action-oriented research agenda. *Journal of Urban Health*, 88(5), pp.886–95.

Frumkin, H., Hess, J., Luber, G., Malilay, J. & McGeehin, M., 2008. Climate change: the public health response. *American Journal of Public Health*, 98(3), pp.435–445.

Frumkin, H., McMichael, A.J. & Hess, J.J., 2008. Climate change and the health of the public. *American Journal of Preventive Medicine*, 35(5), pp.401–2.

Funtowicz, S.O. & Ravetz, J.R., 1993. Science for the post-normal age. *Futures*, 25(7), pp.739–755.

Füssel, H.-M., 2008. Assessing adaptation to the health risks of climate change: what guidance can existing frameworks provide? *International Journal of Environmental Health Research*, 18(1), pp.37–63.

Füssel, H.-M. & Klein, R.J.T., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*, 75(3), pp.301–329.

Füssel, H.-M. & Klein, R.J.T., 2004. Conceptual frameworks of adaptation to climate change and their applicability to human health. Available at: http://www.pik-potsdam.de/research/publications/pikreports/.files/pr91.pdf [Accessed March 27, 2015].

Gabriel, K.M. & Endlicher, W.R., 2011. Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. *Environmental Pollution*, 159(8-9), pp.2044–2050.

Gallopín, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, 16(3), pp.293–303.

Gardiner, S.M. & Hartzell-Nichols, L., 2012. Ethics and global climate change. *Nature Education Knowledge*, 3(10), p.5.

Garrelts, H. & Lange, H., 2011. Path dependencies and path change in complex fields of action: climate adaptation policies in Germany in the realm of flood risk management. *Ambio*, 40(2), pp.200–209.

German Federal Ministry for the Environment Nature Conservation and Nuclear Safety, 2002. *Climate Change and Conflict*, Berlin: German Federal Ministry for the Environment Nature Conservation and Nuclear Safety.

Gern, L., 2005. The biology of the Ixodes ricinus tick. *Therapeutische Umschau*, 62(11), pp.707–712.

Global Biodiversity Information Facility, 2013. Global Biodiversity Information Facility. Available at: www.gbif.org [Accessed March 18, 2015].

Glutting, J., 2011. *Excess heat-related mortality in micro-urban heat islands: a case-only study in Barcelona*. Vrije Universiteit Amsterdam.

Goggins, W.B., Chan, E.Y.Y., Ng, E., Ren, C. & Chen, L., 2012. Effect modification of the association between short-term meteorological factors and mortality by urban heat islands in Hong Kong. *PloS One*, 7(6), p.e38551.

Gore, C., 1993. Entitlement relations and “unruly” social practices: a comment on the work of Amartya Sen. *Journal of Development Studies*, 29(3), pp.429–460.

Gosling, S.N., Lowe, J., McGregor, G., Pelling, M. & Malamud, B., 2009. Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. *Climatic Change*, 92(3), pp.299–341.

Gosling, S.N., McGregor, G.R. & Lowe, J.A., 2011. The benefits of quantifying climate model uncertainty in climate change impacts assessment: an example with heat-related mortality change estimates. *Climatic Change*, 112(2), pp.217–231.

Gostin, L.O. & Powers, M., 2006. What does social justice require for the public's health? Public health ethics and policy imperatives. *Health Affairs*, 25(4), pp.1053–60.

Guha-Sapir, D., Hoyois, P. & Below, R., 2012. *Annual Disaster Statistical Review 2012: the numbers and trends*, Brussels: CRED.

Guo, Y. et al., 2014. Global variation in the effects of ambient temperature on mortality: a systematic evaluation. *Epidemiology*, 25(6), pp.781–789.

Gupta, S. et al., 2012. Electric fans for reducing adverse health impacts in heatwaves. *The Cochrane Database of Systematic Reviews*, 7.

Haines, A. et al., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *Lancet*, 374(9707), pp.2104–2114.

Hajat, S., O'Connor, M. & Kosatsky, T., 2010. Health effects of hot weather: from awareness of risk factors to effective health protection. *Lancet*, 375(9717), pp.856–863.

Hajat, S., Vardoulakis, S., Heaviside, C. & Eggen, B., 2014. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *Journal of Epidemiology and Community Health*, 68(7), pp.641–648.

Halady, I.R. & Rao, P.H., 2010. Does awareness to climate change lead to behavioral change? *International Journal of Climate Change Strategies and Management*, 2(1), pp.6–22.

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D. & Tucker, G., 2008. The effect of heat waves on mental health in a temperate Australian city. *Environmental Health Perspectives*, 116(10), pp.1369–1375.

Hansson, S.O., 2012. A panorama of the philosophy ofrRisk. In S. Roeser et al., eds. *Handbook of Risk Theory. Volume 1.* Dordrecht [u.a.]: Springer, pp. 27–54.

Haque, A.N., Grafakos, S. & Huijsman, M., 2012. Participatory integrated assessment of flood protection measures for climate adaptation in Dhaka. *Environment and Urbanization*, 24(1), pp.197–213.

Harlan, S.L., Brazel, A.J., Prashad, L., Stefanov, W.L. & Larsen, L., 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*, 63(11), pp.2847–63.

Harlan, S.L., Declet-Barreto, J.H., Stefanov, W.L. & Petitti, D.B., 2013. Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. *Environmental Health Perspectives*, 121(2), pp.197–204.

Harlan, S.L. & Ruddell, D.M., 2011. Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Current Opinion in Environmental Sustainability*, 3, pp.126–134.

Harrison, P.A., Holman, I.P. & Berry, P.M., 2015. Assessing cross-sectoral climate change impacts, vulnerability and adaptation: an introduction to the CLIMSAVE project. *Climatic Change*, 128(3-4), pp.153–167.

Hartz, D., Brazel, A.J. & Golden, J.S., 2013. A comparative climate analysis of heat-related emergency 911 dispatches: Chicago, Illinois and Phoenix, Arizona USA 2003 to 2006. *International Journal of Biometeorology*, 57(5), pp.669–678.

Hartz, D., Golden, J.S., Sister, C., Chuang, W.-C. & Brazel, A.J., 2012. Climate and heat-related emergencies in Chicago, Illinois (2003–2006). *International Journal of Biometeorology*, 56(1), pp.71–83.

Heimann, T. & Christmann, G.B., 2013. *Klimawandel in den deutschen Küstenstädten und -gemeinden*, Erkner: IRS Leibniz Institut für Regionalentwicklung und Strukturplanung.

Hess, J.J., Eidson, M., Tlumak, J.E., Raab, K.K. & Luber, G., 2014. An evidence-based Public Health approach to climate change adaptation. *Environmental Health Perspectives*, 122(11), pp.1177–1186.

Hess, J.J., Malilay, J.N. & Parkinson, A.J., 2008. Climate change: the importance of place. *American Journal of Preventive Medicine*, 35(5), pp.468–78.

Hess, J.J., Schramm, P.J. & Luber, G., 2014. Public Health and climate change adaptation at the federal level: one agency's response to Executive Order 13514. *American Journal of Public Health*, 104(3), pp.e22–30.

Hewitt, K., 1997. *Regions of risk: a geographical introduction to disasters*, Harlow, Essex: Longman.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25(15), pp.1965–1978.

Hinkel, J. et al., 2013. *PROVIA guidance on assessing vulnerability, impacts and adaptation to climate change. Consultation document*, Nairobi: United Nations Environment Programme (UNEP).

Hochrainer-Stigler, S., Mechler, R., Pflug, G. & Williges, K., 2014. Funding public adaptation to climate-related disasters. Estimates for a global fund. *Global Environmental Change*, 25, pp.87–96.

Hosking, J. & Campbell-Lendrum, D., 2012. How well does climate change and human health research match the demands of policymakers? A scoping review. *Environmental Health Perspectives*, 120(8), pp.1076–82.

Huang, C., Barnett, A.G., Wang, X., Vaneckova, P., FitzGerald, G. & Tong, S., 2011. Projecting future heat-related mortality under climate change scenarios: a systematic review. *Environmental Health Perspectives*, 119(12), pp.1681–1690.

Hulme, M., Dessai, S., Lorenzoni, I. & Nelson, D.R., 2009. Unstable climates: exploring the statistical and social constructions of "normal" climate. *Geoforum*, 40(2), pp.197–206.

Illari, P.M. ed., 2011. *Causality in the sciences*, Oxford [u.a.]: Oxford Univ. Press.

Imura, H. & Schreurs, M.A. eds., 2005. *Environmental policy in Japan*, Cheltenham: Edward Elgar in association with the World Bank.

IPCC, 2014a. *IPCC 5th Assessment Report Climate Change 2014: Impacts, Adaptation, and Vulnerability*, Cambridge: Cambridge University Press.

IPCC, 2012a. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* C. B. Field et al., eds., Cambridge and New York: Cambridge University Press.

IPCC, 2014b. Summary for policymakers. In C. B. Field et al., eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press, pp. 1–32.

IPCC, 2013. Summary for policymakers. In T. F. Stocker et al., eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

IPCC, 2012b. Summary for Policymakers. In C. B. Field et al., eds. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press, pp. 1–19.

Ireland, P. & Thomalla, F., 2011. The role of collective action in enhancing communities' adaptive capacity to environmental risk: an exploration of two case studies from Asia. *PLoS Currents Disasters*, 1, p.RRN1279.

Jackson, J.E. et al., 2010. Public health impacts of climate change in Washington State: projected mortality risks due to heat events and air pollution. *Climatic Change*, 102, pp.159–186.

Jackson, L.L. & Rosenberg, H.R., 2010. Preventing heat-related illness among agricultural workers. *Journal of Agromedicine*, 15(3), pp.200–15.

Jakubicka, T., Vos, F., Phalkey, R., Marx, M. & Guha-Sapir, D., 2010. *Health impacts of floods in Europe. Data gaps and information needs from a spatial perspective. A Microdis report*, Heidelberg and Brussels: Universitätsklinikum Heidelberg; Centre for Research on the Epidemiology of disasters (CRED).

Janssen, M.A. & Ostrom, E., 2006. Resilience, vulnerability, and adaptation: a cross-cutting theme of the International Human Dimensions Programme on Global Environmental Change. *Global Environmental Change*, 16(3), pp.237–239.

Kakota, T., Nyariki, D., Mkwambisi, D. & Kogi-Makau, W., 2011. Gender vulnerability to climate variability and household food insecurity. *Climate and Development*, 3(4), pp.298–309.

Kalnay, E. & Cai, M., 2003. Impact of urbanization and land-use change on climate. *Nature*, 423(6939), pp.528–31.

Kasperson, J.X., Kasperson, R.E., Turner II, B.L., Hsieh, W. & Schiller, A., 2005. Vulnerability to global environmental change. In J. X. Kasperson & R. E. Kasperson, eds. *The Social Contours of Risk Vol. II: Risk Analysis, Corporations, and the Globalization of Risk*. London: Earthscan, pp. 245–285.

Kates, R.W., Travis, W.R. & Wilbanks, T.J., 2012. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America*, 109(19), pp.7156–61.

KC, S. & Lutz, W., 2014. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change*, In press.

Keatinge, W.R., Coleshaw, S.R., Easton, J.C., Cotter, F., Mattock, M.B. & Chelliah, R., 1986. Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. *The American Journal of Medicine*, 81(5), pp.795–800.

Keene, D.E. & Padilla, M.B., 2014. Spatial stigma and health inequality. *Critical Public Health*, pp.1–13.

Keim, M.E., 2008. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *American Journal of Preventive Medicine*, 35(5), pp.508–16.

Kelle, U., 2008. *Die Integration qualitativer und quantitativer Methoden in der empirischen Sozialforschung: theoretische Grundlagen und methodologische Konzepte* 2nd ed., Wiesbaden: VS Verlag für Sozialwissenschaften.

Kinney, P.L., 2008. Climate change, air quality, and human health. *American Journal of Preventive Medicine*, 35(5), pp.459–467.

Kjellstrom, T., Butler, A.J., Lucas, R.M. & Bonita, R., 2010. Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. *International Journal of Public Health*, 55(2), pp.97–103.

Kjellstrom, T. & McMichael, A.J., 2013. Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Global Health Action*, 6, p.20816.

Klein Rosenthal, J., 2010. *Evaluating the impact of the urban heat island on public health: Spatial and social determinants of heat-related mortality in New York City*. Columbia University.

Klein Rosenthal, J., Kinney, P.L. & Metzger, K.B., 2014. Intra-urban vulnerability to heat-related mortality in New York City, 1997-2006. *Health & Place*, 30C, pp.45–60.

Klein Rosenthal, J., Sclar, E.D., Kinney, P.L., Knowlton, K., Crauderueff, R. & Brandt-Rauf, P.W., 2007. Links between the built environment, climate and population health:

interdisciplinary environmental change research in New York City. *Annals of the Academy of Medicine, Singapore*, 36(10), pp.834–846.

Klinenberg, E., 2006. Blaming the victims: hearsay, labeling, and the hazards of quick-hit disaster ethnography. *American Sociological Review*, 71(4), pp.679–688.

Klinenberg, E., 1999. Denaturalizing disaster: a social autopsy of the 1995 Chicago heat wave. *Theory and Society*, 28(2), pp.239–295.

Knutson, T.R. et al., 2010. Tropical cyclones and climate change. *Nature Geoscience*, 3(3), pp.157–163.

Köhler, M. & Michaelowa, A., 2013. *Saved health, saved wealth: an approach to quantifying the benefits of climate change adaptation*, Eschborn: Deutsche Gesellschaft für International Zusammenarbeit (GIZ) GmbH.

Kovats, R.S. & Hajat, S., 2008. Heat stress and public health: a critical review. *Annual Review of Public Health*, 29, pp.41–55.

Krausing, J. et al., 2013. *Building resilience: integrating climate and disaster risk into development*, Washington DC: The World Bank.

Kriticos, D.J. et al., 2012. CliMond: global high-resolution historical and future scenario climate surfaces for bioclimatic modelling. *Methods in Ecology and Evolution*, 3(1), pp.53–64.

Kuckartz, U., Dresing, T., Rädiker, S. & Stefer, C., 2008. *Qualitative Evaluation* 2nd ed., Wiesbaden: VS Verlag für Sozialwissenschaften.

Kukarenko, N., 2011. Climate change effects on human health in a gender perspective: some trends in Arctic research. *Global Health Action*, 4, p.7913.

Laaidi, K. et al., 2012. The impact of heat islands on mortality in Paris during the August 2003 heat wave. *Environmental Health Perspectives*, 120(2), pp.254–9.

Lamhauge, N., Lanzi, E. & Agrawala, S., 2013. The use of indicators for monitoring and evaluation of adaptation: lessons from development cooperation agencies. *Climate and Development*, 5(3), pp.229–241.

Lane, K. et al., 2014. Extreme heat awareness and protective behaviors in New York City. *Journal of Urban Health*, 91(3), pp.403–414.

Lee, H.C., Lin, H.C., Tsai, S.Y., Li, C.Y., Chen, C.C. & Huang, C.C., 2006. Suicide rates and the association with climate: a population-based study. *Journal of Affective Disorders*, 92(2-3), pp.221–226.

Leone, M. et al., 2013. A time series study on the effects of heat on mortality and evaluation of heterogeneity into European and Eastern-Southern Mediterranean cities: results of EU CIRCE project. *Environmental Health*, 12, p.55.

Lesnikowski, A.C., Ford, J.D., Berrang-Ford, L., Barrera, M. & Heymann, J., 2013. How are we adapting to climate change? A global assessment. *Mitigation and Adaptation Strategies for Global Change*, 20(2), pp.277–293.

Lim, Y.-K., Cai, M., Kalnay, E. & Zhou, L., 2005. Observational evidence of sensitivity of surface climate changes to land types and urbanization. *Geophysical Research Letters*, 32(22), p.L22712.

Lorenc, T. & Oliver, K., 2014. Adverse effects of public health interventions: a conceptual framework. *Journal of Epidemiology and Community Health*, 68(3), pp.288–90.

Lorenc, T., Petticrew, M., Welch, V. & Tugwell, P., 2013. What types of interventions generate inequalities? Evidence from systematic reviews. *Journal of Epidemiology and Community Health*, 67(2), pp.190–3.

Loughnan, M.E., Nicholls, N. & Tapper, N.J., 2010. The effects of summer temperature, age and socioeconomic circumstance on Acute Myocardial Infarction admissions in Melbourne, Australia. *International Journal of Health Geographics*, 9, p.41.

Lowe, D., Ebi, K.L. & Forsberg, B., 2013. Factors increasing vulnerability to health effects before, during and after floods. *International Journal of Environmental Research and Public Health*, 10(12), pp.7015–67.

Lowe, D., Ebi, K.L. & Forsberg, B., 2011. Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. *International Journal of Environmental Research and Public Health*, 8(12), pp.4623–4648.

Macintyre, S., 1997. What are spatial effects and how can we measure them? In A. Dale, ed. *Exploiting national survey data: the role of locality and spatial effects*. Manchester: University of Manchester, Faculty of Economic and Social Studies, pp. 1–17.

Macintyre, S., Ellaway, A. & Cummins, S., 2002. Place effects on health: how can we conceptualise, operationalise and measure them? *Social Science & Medicine*, 55(1), pp.125–139.

Marinucci, G., Luber, G., Uejio, C., Saha, S. & Hess, J., 2014. Building resilience against climate effects - a novel framework to facilitate climate readiness in Public Health agencies. *International Journal of Environmental Research and Public Health*, 11(6), pp.6433–6458.

Marmot, M., Allen, J., Bell, R., Bloomer, E. & Goldblatt, P., 2012. WHO European review of social determinants of health and the health divide. *Lancet*, 380(9846), pp.1011–29.

Martinez, G.S., Imai, C. & Masumo, K., 2011. Local heat stroke prevention plans in Japan: Characteristics and elements for public health adaptation to climate change. *International Journal of Environmental Research and Public Health*, 8(12), pp.4563–4581.

McCarthy, M.P., Best, M.J. & Betts, R. a., 2010. Climate change in cities due to global warming and urban effects. *Geophysical Research Letters*, 37, p.L09705.

McGeehin, M.A. & Mirabelli, M., 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environmental Health Perspectives*, 109 Suppl, pp.185–189.

McMichael, A.J., Campbell-Lendrum, D.H., et al. eds., 2003. *Climate change and human health: risks and responses*, Geneva: World Health Organization.

McMichael, A.J. et al., 2004. Global climate change. In M. Ezzati et al., eds. *Comparative Quantification of Health Risks. Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Geneva: World Health Organization, pp. 1543–1649.

McMichael, A.J., 2013. Impediments to comprehensive research on climate change and health. *International Journal of Environmental Research and Public Health*, 10(11), pp.6096–105.

McMichael, A.J. et al., 2008. International study of temperature, heat and urban mortality: the "ISOTHURM" project. *International Journal of Epidemiology*, 37(5), pp.1121–1131.

McMichael, A.J. & Githeko, A., 2001. Human health. In J. J. McCarthy et al., eds. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press, pp. 451–485.

McMichael, A.J., Lucas, R., Ponsonby, A.-L. & Edwards, S.J., 2003. Stratospheric ozone depletion, ultraviolet radiation and health. In A. J. McMichael et al., eds. *Climate change and human health. Risks and responses*. Geneva: World Health Organization, pp. 159–180.

McMichael, A.J., Montgomery, H. & Costello, A., 2012. Health risks, present and future, from global climate change. *BMJ*, 344, p.e1359.

Mechler, R. et al., 2014. Managing unnatural disaster risk from climate extremes. *Nature Climate Change*, 4(4), pp.235–237.

Morello-Frosch, R., Zuk, M., Jerrett, M., Shamasunder, B. & Kyle, A.D., 2011. Understanding the cumulative impacts of inequalities in environmental health: implications for policy. *Health Affairs*, 30(5), pp.879–87.

Morin, C.W., Comrie, A.C. & Ernst, K., 2013. Climate and dengue transmission: evidence and implications. *Environmental Health Perspectives*, 121, pp.1264–1272.

Morris, G.P., 2010. Ecological public health and climate change policy. *Perspectives in Public Health*, 130(1), pp.34–40.

Morss, R.E., Wilhelmi, O. V., Meehl, G.A. & Dilling, L., 2011. Improving societal outcomes of extreme weather in a changing climate: an integrated perspective. *Annual Review of Environment and Resources*, 36(1), pp.1–25.

Moss, R.H. et al., 2010. The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282), pp.747–56.

Nakicenovic, N. et al., 2000. *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change* N. Nakicenovic & R. Swart, eds., Cambridge: Cambridge University Press.

Napier, A.D. et al., 2014. Culture and health. *The Lancet*, 384, pp.1607–39.

Nchito, W.S., 2007. Flood risk in unplanned settlements in Lusaka. *Environment and Urbanization*, 19(2), pp.539–551.

Nelson, R. et al., 2010. The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. *Environmental Science & Policy*, 13(1), pp.18–27.

Nielsen, J.Ø. & Reenberg, A., 2010. Cultural barriers to climate change adaptation: a case study from Northern Burkina Faso. *Global Environmental Change*, 20(1), pp.142–152.

Nitschke, M., Tucker, G.R. & Bi, P., 2007. Morbidity and mortality during heatwaves in metropolitan Adelaide. *The Medical Journal of Australia*, 187(11-12), pp.662–665.

O'Brien, K., 2011. Global environmental change II: From adaptation to deliberate transformation. *Progress in Human Geography*, 36(5), pp.667–676.

O'Brien, K., Eriksen, S., Nygaard, L.P. & Schjolden, A., 2007. Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy*, 7(1), pp.73–88.

O'Brien, K., Eriksen, S., Schjolden, A. & Nygaard, L., 2004. *What's in a word? Conflicting interpretations of vulnerability in climate change research*, Oslo: CICERO (Center for International Climate and Environmental Research).

O'Neill, B.C. et al., 2013. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic Change*, 122(3), pp.387–400.

Okely, J., 2012. *Anthropological practice*, London [u.a.]: Berg.

Oliveira, S., Andrade, H. & Vaz, T., 2011. The cooling effect of green spaces as a contribution to the mitigation of urban heat: a case study in Lisbon. *Building and Environment*, 46(11), pp.2186–2194.

Ono, M., 2012. Information system of heat-disorders and prevention. *Nihon Rinsho. Japanese Journal of Clinical Medicine*, 70(6), pp.1039–1045.

Page, L.A., Hajat, S. & Kovats, R.S., 2007. Relationship between daily suicide counts and temperature in England and Wales. *The British Journal of Psychiatry: The Journal of Mental Science*, 191, pp.106–112.

Palmary, I., 2011. "In your experience:" research as gendered cultural translation. *Gender, Place & Culture*, 18(1), pp.99–113.

Panic, M. & Ford, J.D., 2013. A review of national-level adaptation planning with regards to the risks posed by climate change on infectious diseases in 14 OECD nations. *International Journal of Environmental Research and Public Health*, 10(12), pp.7083–109.

Patrick, R., Capetola, T., Townsend, M. & Nuttman, S., 2012. Health promotion and climate change: exploring the core competencies required for action. *Health Promotion International*, 27(4), pp.475–85.

Patt, A., 2012. Multi-level climate adaptation policy and causation narratives. *Geografisk Tidsskrift-Danish Journal of Geography*, 112(2), pp.174–182.

Patz, J.A., Campbell-Lendrum, D., Holloway, T. & Foley, J.A., 2005. Impact of regional climate change on human health. *Nature*, 438(7066), pp.310–7.

Patz, J.A., Epstein, P.R., Burke, T.A. & Balbus, J.M., 1996. Global climate change and emerging infectious diseases. *JAMA*, 275(3), pp.217–23.

Patz, J.A., Frumkin, H., Holloway, T., Vimont, D.J. & Haines, A., 2014. Climate change. *JAMA*, 312(15), pp.1565–1580.

Picketts, I.M., Curry, J., Déry, S.J. & Cohen, S.J., 2013. Learning with practitioners: climate change adaptation priorities in a Canadian community. *Climatic Change*, 118(2), pp.321–337.

Porta, M.S. & International Epidemiological Association eds., 2008. *A dictionary of epidemiology* 5th ed., Oxford: Oxford University Press.

Preet, R., Nilsson, M., Schumann, B. & Evengård, B., 2010. The gender perspective in climate change and global health. *Global Health Action*, 3, p.5720.

Preti, A., Lentini, G. & Maugeri, M., 2007. Global warming possibly linked to an enhanced risk of suicide: data from Italy, 1974-2003. *Journal of Affective Disorders*, 102(1-3), pp.19–25.

Pronyk, P.M., Schaefer, J., Somers, M.-A. & Heise, L., 2013. Evaluating structural interventions in public health: challenges, options and global best-practice. In M. Sommer & R. Parker, eds. *Structural Approaches in Public Health*. Routledge, pp. 187–205.

Prüss-Üstün, A. & Corvalán, C., 2006. *Preventing disease through healthy environments. Towards an estimate of the environmental burden of disease*, Geneva: World Health Organization.

Reid, C.E. & Gamble, J.L., 2009. Aeroallergens, allergic disease, and climate change: impacts and adaptation. *EcoHealth*, 6(3), pp.458–470.

Rock, M.J., Degeling, C. & Blue, G., 2013. Toward stronger theory in critical public health: insights from debates surrounding posthumanism. *Critical Public Health*, 24(3), pp.337–348.

Rosenthal, J.P. & Jessup, C.M., 2009. Global climate change and health: developing a research agenda for the NIH. *Transactions of the American Clinical and Climatological Association*, 120, pp.129–141.

Rothman, K., Greenland, S. & Lash, T.L., 2008. *Modern Epidemiology* 3rd ed., Philadelphia, Pa.: Lippincott, Williams & Wilkins.

Rubel, F. et al., 2014. The first German map of georeferenced ixodid tick locations. *Parasites & Vectors*, 7(1), p.477.

Rychetnik, L., Frommer, M., Hawe, P. & Shiell, A., 2002. Criteria for evaluating evidence on public health interventions. *Journal of Epidemiology and Community Health*, 56(2), pp.119–127.

Rychetnik, L., Hawe, P., Waters, E., Barratt, A. & Frommer, M., 2004. A glossary for evidence based public health. *Journal of Epidemiology and Community Health*, 58(7), pp.538–45.

Sackett, D.L., Rosenberg, W.M.C., Gray, J.A.M., Haynes, R.B. & Richardson, W.S., 1996. Evidence based medicine: what it is and what it isn't. *BMJ*, 312(7023), pp.71–72.

Saks, M., 2007. *Researching health: qualitative, quantitative and mixed methods*, Los Angeles, Calif. [u.a.]: SAGE Publ.

Salehyan, I. & Hendrix, C.S., 2014. Climate shocks and political violence. *Global Environmental Change*, 28, pp.239–250.

Van de Sand, I., 2012. *Assessing Vulnerability to Climate Variability and Change. Participatory assessment approach and Kenyan case study*, Bonn: German Development Institute (DIE).

Sanderson, D., 2000. Cities, disasters and livelihoods. *Environment and Urbanization*, 12(2), pp.93–102.

Sauerborn, R. & Ebi, K., 2012. Climate change and natural disasters: integrating science and practice to protect health. *Global Health Action*, 5, p.19295.

Sawford, K., Dhand, N.K., Toribio, J.-A.L. & Taylor, M.R., 2014. The use of a modified Delphi approach to engage stakeholders in zoonotic disease research priority setting. *BMC Public Health*, 14(1), p.182.

Schellnhuber, H.J. et al., 2013. *Turn down the heat: climate extremes, regional impacts, and the case for resilience - full report*, Washington, D.C.: The World Bank.

Schipper, E.L.F., 2006. Conceptual history of adaptation in the UNFCCC process. *Review of European Community and International Environmental Law*, 15(1), pp.82–92.

Schmidhuber, J. & Tubiello, F.N., 2007. Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 104(50), pp.19703–19708.

Schreurs, M.A. & Tiberghien, Y., 2007. Multi-level reinforcement: explaining European Union leadership in climate change mitigation. *Global Environmental Politics*, 7(4), pp.19–46.

Schwartz, J., 2005. Who is sensitive to extremes of temperature? A case-only analysis. *Epidemiology*, 16(1), pp.67–72.

Schwartz, J. & Zanobetti, A., 2000. Using meta-smoothing to estimate dose-response trends across multiple studies, with application to air pollution and daily death. *Epidemiology*, 11(6), pp.666–72.

SEI, 2012. *Can "1°C of climate change adaptation" replace "1°C of mitigation"? Why economic models can't solve policy dilemmas*, Stockholm: SEI.

Semenza, J.C., Herbst, S., et al., 2012. Climate change impact assessment of food- and waterborne diseases. *Critical Reviews in Environmental Science and Technology*, 42(8), pp.857–890.

Semenza, J.C. & Menne, B., 2009. Climate change and infectious diseases in Europe. *The Lancet Infectious Diseases*, 9(6), pp.365–75.

Semenza, J.C., Suk, J.E., Estevez, V., Ebi, K.L. & Lindgren, E., 2012. Mapping climate change vulnerabilities to infectious diseases in Europe. *Environmental Health Perspectives*, 120(3), pp.385–92.

Sheffield, P.E., Herrera, J.G.R., Lemke, B., Kjellstrom, T. & Romero, L.E.B., 2013. Current and future heat stress in Nicaraguan work places under a changing climate. *Industrial Health*, 51(1), pp.123–7.

Shonkoff, S.B., Morello-Frosch, R., Pastor, M. & Sadd, J., 2011. The climate gap: environmental health and equity implications of climate change and mitigation policies in California—a review of the literature. *Climatic Change*, 109(S1), pp.485–503.

Silverman, D., 2011. *Doing qualitative research* 3rd ed., Los Angeles [u.a.]: SAGE Publ.

Skinner, E., 2011. *Gender and climate change. Overview report.* BRIDGE, ed., Brighton: Institute of Development Studies.

Smit, B., Burton, I., Klein, R.J.T. & Wandel, J., 2000. An anatomy of adaptation to climate change and variability. *Climatic Change*, 45(1), pp.223–251.

Smith, K.R. et al., 2014. Human health: impacts, adaptation and co-benefits. In C. B. Field et al., eds. *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A:*

Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press, pp. 709–754.

Solecki, W., Leichenko, R. & O'Brien, K., 2011. Climate change adaptation strategies and disaster risk reduction in cities: connections, contentions, and synergies. *Current Opinion in Environmental Sustainability*, 3(3), pp.135–141.

Sovacool, B.K., 2013. Adaptation: the complexity of climate justice. *Nature Climate Change*, 3(11), pp.959–960.

Spearman, M. & McGray, H., 2011. *Making adaptation count. Concepts and options for monitoring and evaluation of climate change adaptation*, Eschborn: GIZ, BMZ, World Resources Institute.

Stockwell, D. & Peters, D., 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science*, 13(2), pp.143–158.

Stone, B., Hess, J.J. & Frumkin, H., 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? *Environmental Health Perspectives*, 118(10), pp.1425–1428.

Stott, R., 2010. Population and climate change: moving toward gender equality is the key. *Journal of Public Health (Oxford, England)*, 32(2), pp.159–160.

Takebayashi, H., Kimura, Y. & Kyogoku, S., 2014. Study on the appropriate selection of urban heat island measure technologies to urban block properties. *Sustainable Cities and Society*, 13, pp.217–222.

Tan, J. et al., 2010. The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, 54(1), pp.75–84.

Tatara, K. & Okamoto, E., 2009. *Japan Health System Review* S. Allin & R. Matsuda, eds., Copenhagen: World Health Organization.

Temple, B. & Young, A., 2004. Qualitative research and translation dilemmas. *Qualitative Research*, 4(2), pp.161–178.

Terry, G., 2009. *Climate change and gender justice*, Warwickshire: Practical Action Publishing and Oxfam GB.

Thomas, P., Swaminathan, A. & Lucas, R.M., 2012. Climate change and health with an emphasis on interactions with ultraviolet radiation: a review. *Global Change Biology*, 18(8), pp.2392–2405.

Thomas, S., Tjaden, N., van den Bos, S. & Beierkuhnlein, C., 2014. Implementing cargo movement into climate based risk assessment of vector-borne diseases. *International Journal of Environmental Research and Public Health*, 11(3), pp.3360–3374.

Thow, A.M., Downs, S. & Jan, S., 2014. A systematic review of the effectiveness of food taxes and subsidies to improve diets: understanding the recent evidence. *Nutrition Reviews*, 72(9), pp.551–65.

Thurston, G.D., 2013. Mitigation policy: health co-benefits. *Nature Climate Change*, 3(10), pp.863–864.

Tierney, K., 2012. Disaster governance: social, political, and economic dimensions. *Annual Review of Environment and Resources*, 37(1), pp.341–363.

Tobias, A., Armstrong, B., Gasparrini, A. & Diaz, J., 2014. Effects of high summer temperatures on mortality in 50 Spanish cities. *Environmental Health*, 13(1), p.48.

Tobias, A., Armstrong, B., Zuza, I., Gasparrini, A., Linares, C. & Diaz, J., 2012. Mortality on extreme heat days using official thresholds in Spain: a multi-city time series analysis. *BMC Public Health*, 12(1), p.133.

Toloo, G., Fitzgerald, G., Aitken, P., Verrall, K. & Tong, S., 2013. Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence. *International Journal of Public Health*, 58(5), pp.667–81.

Tomlinson, C.J., Chapman, L., Thornes, J.E. & Baker, C.J., 2011. Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK. *International Journal of Health Geographics*, 10(1), p.42.

Uejio, C.K., Wilhelmi, O. V, Golden, J.S., Mills, D.M., Gulino, S.P. & Samenow, J.P., 2011. Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Geographies of Care*, 17(2), pp.498–507.

UN-HABITAT, 2013. *State of the World's Cities 2012/2013. Prosperity of cities.*, New York: Earthscan.

United Nations Centre for Regional Development, 2003. *Sustainability in grass-roots initiatives. Focus on community based disaster management.* R. Shaw & K. Okazaki, eds., Hyogo: United Nations Centre for Regional Development.

United Nations Department of Economic and Social Affairs. Population Division, 2014. World Urbanization Prospects, the 2014 Revision. Available at: http://esa.un.org/unpd/wup/index.htm [Accessed March 19, 2015].

United Nations Framework Convention on Climate Change, 2014a. Background on the UNFCCC: The international response to climate change. Available at: http://unfccc.int/essential_background/items/6031.php [Accessed March 20, 2015].

United Nations Framework Convention on Climate Change, 1992. United Nations Framework Convention on Climate Change. Available at: http://unfccc.int/resource/docs/convkp/conveng.pdf [Accessed February 2, 2015].

United Nations Framework Convention on Climate Change, 2014b. Workstreams: adaptation. Available at: http://unfccc.int/adaptation/workstreams/items/6995.php [Accessed March 20, 2015].

United States Environmental Protection Agency, 2006. *Excessive heat events guidebook*, Washington, DC: U.S. EPA.

Vargo, J., Habeeb, D. & Stone, B., 2013. The importance of land cover change across urban–rural typologies for climate modeling. *Journal of Environmental Management*, 114, pp.243–252.

Van Vuuren, D.P. et al., 2012. A proposal for a new scenario framework to support research and assessment in different climate research communities. *Global Environmental Change*, 22(1), pp.21–35.

Van Vuuren, D.P. et al., 2011. The representative concentration pathways: an overview. *Climatic Change*, 109(1-2), pp.5–31.

Van Vuuren, D.P. & Carter, T.R., 2013. Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. *Climatic Change*, 122(3), pp.415–429.

Walker, R., Hassall, J., Chaplin, S., Congues, J., Bajayo, R. & Mason, W., 2011. Health promotion interventions to address climate change using a primary health care approach: a literature review. *Health Promotion Journal of Australia*, 22 Spec No, pp.S6–12.

Wardekker, J.A., de Jong, A., van Bree, L., Turkenburg, W.C. & van der Sluijs, J.P., 2012. Health risks of climate change: an assessment of uncertainties and its implications for adaptation policies. *Environmental Health*, 11(1), p.67.

Watt, S. & Chamberlain, J., 2011. Water, climate change, and maternal and newborn health. *Current Opinion in Environmental Sustainability*, 3(6), pp.491–496.

West, J.J. et al., 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change*, 3(10), pp.885–889.

Wilby, R.L. & Dessai, S., 2010. Robust adaptation to climate change. *Weather*, 65(7), pp.180–185.

Wiley, L.F., 2010. Mitigation/adaptation and health: health policymaking in the global response to climate change and implications for other upstream determinants. *The Journal of Law, Medicine & Ethics*, 38(3), pp.629–639.

Wilhelmi, O. V & Hayden, M.H., 2010. Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters*, 5(1), p.14021.

Wise, R.M. et al., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, 28, pp.325–336.

Wisner, B., 2007. Regions at risk or people at risk? Wie natürlich sind "Naturkatastrophen"? *Geographische Rundschau*, 59(10), pp.12–18.

Wisner, B., Blaikie, P., Cannon, T. & Davis, I., 2004. *At risk* 2nd ed., London [u.a.]: Routledge.

Van der Woerd, D.F. et al., 2012. How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, 64, pp.30–38.

Wolf, J., Adger, W.N., Lorenzoni, I., Abrahamson, V. & Raine, R., 2010. Social capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities. *Global Environmental Change*, 20(1), pp.44–52.

Wolf, T., Martinez, G.S., Cheong, H.-K., Williams, E. & Menne, B., 2014. Protecting health from climate change in the WHO European region. *International Journal of Environmental Research and Public Health*, 11(6), pp.6265–80.

Woodward, A., 2014. Heat, cold and climate change. *Journal of Epidemiology and Community Health*, 68(7), pp.595–596.

World Health Organization, 2012. *Atlas of health and climate*, Geneva: World Health Organization.

World Health Organization, 2002. *Environmental health in emergencies and disasters. A practical guide.* B. Wisner & J. Adams, eds., Geneva: World Health Organization.

World Health Organization, 2006. *EUROHeat: Improving public health responsens to extreme weather/heat waves.* World Health Organization Regional Office for Europe, ed., Copenhagen.

World Health Organization, 2011. *Gender, climate change and health*, Geneva: World Health Organization.

World Health Organization, 2014a. Health in all policies (HiAP) framework for country action. *Health Promotion International*, 29 Suppl 1, pp.i19–28.

World Health Organization, 2014b. *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s* S. Hales et al., eds., Geneva: World Health Organization.

World Health Organization Centre for Health Development, 2009. *Climate change exposures, chronic diseases and mental health in urban populations: a threat to health security, particularly for the poor and disadvantaged.*, Kobe: WHO Centre for Health Development.

World Health Organization Regional Office for Europe, 2002. *Floods: climate change and adaptation strategies for human health. Report on a WHO meeting.*, Copenhagen: World Health Organization.

Wutich, A. & Ragsdale, K., 2008. Water insecurity and emotional distress: coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. *Social Science & Medicine*, 67(12), pp.2116–2125.

Yamada, S. & Galat, A., 2014. Typhoon Yolanda/Haiyan and climate justice. *Disaster Medicine and Public Health Preparedness*, 8(5), pp.432–435.

Yeo, T.P., 2004. Heat Stroke: A comprehensive review. *AACN Clinical Issues: Advanced Practice in Acute & Critical Care*, 15(2), pp.280–293.

Yin, R.K., 2009. *Case study research: design and methods* 4th ed., Los Angeles [u.a.]: Sage.

Zhang, Y., Bi, P. & Hiller, J.E., 2008. Climate change and the transmission of vector-borne diseases: a review. *Asia-Pacific Journal of Public Health*, 20(1), pp.64–76.

9 Manuscripts

Article I

Boeckmann, M., & Rohn, I. (2014). **Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review.** *BMC Public Health*, *14*(1), 1112. doi:10.1186/1471-2458-14-1112

Boeckmann and Rohn *BMC Public Health* 2014, **14**:1112
http://www.biomedcentral.com/1471-2458/14/1112

BMC Public Health

RESEARCH ARTICLE Open Access

Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review

Melanie Boeckmann[1,2*] and Ines Rohn[3]

Abstract

Background: Extreme heat is an important public health risk. Climate change will likely increase the temperatures humans are exposed to through exacerbated heat wave intensity and frequency, possibly increasing health risks from heat. To prevent adverse effects on human health, heat prevention plans and climate change adaptation strategies are being implemented. But are these measures effectively reducing heat-related mortality and morbidity? This study assesses the evidence base in 2014.

Methods: We conducted a systematic review of peer-reviewed published literature. We applied a combined search strategy of automated search and journal content search using the electronic databases PubMed, Web of Knowledge, Biological Abstracts, CAB Abstracts and ProQuest Dissertation & Theses A&I. Quality appraisal was conducted using CASP checklists, and we identified recurrent themes in studies with content analysis methodology. We conducted sub-group analyses for two types of studies: survey and interview research on behavioral change and perception, and observational studies with regression.

Results: 30 articles were included in the review. The majority of studies (n = 17) assessed mortality or morbidity reductions with regression analysis. Overall, the assessments report a reduction of adverse effects during extreme heat in places where preventive measures have been implemented. Population perception and behavior change were assessed in five studies, none of which had carried out a pre-test. Two themes emerged from the review: methodological challenges are a major hindrance to rigorous evaluation, and what counts as proof of an effective reduction in adverse health outcomes is disputed.

Conclusions: Attributing health outcomes to heat adaptation remains a challenge. Recent study designs are less rigorous due to difficulties assigning the counterfactual. While sensitivity to heat is decreasing, the examined studies provide inconclusive evidence on individual planned adaptation measures.

Keywords: Heat, Climate change, Effectiveness, Systematic review, Cardiovascular disease, Respiratory disease

Background

Extreme heat is a public health risk [1-3]. In 2013, 58.729 heat stroke diagnoses have been recorded for Japan [4], for example, and the United States Centers for Disease Control report an annual 659 cases (on average) of heat-related deaths between 1999 and 2009 [5]. These numbers are likely underestimated: as the physical effects of heat primarily exacerbate underlying conditions, diagnoses of death as heat-related are of varied quality [6]. Data availability on heat stroke incidence also depends on whether an emergency room or ambulance call occurs, as well as on active collection of such data. Heat increases the risk of dying of preexisting cardiovascular disease [6]; and heat stroke may lead to multiple organ failure [6-8]. Heat-related morbidity and mortality are preventable. Older persons, people taking medications that impair thermoregulation [6], very young children, socially isolated elderly, and people physically active outdoors during very hot periods have

* Correspondence: melanie.boeckmann@bips.uni-bremen.de
[1]Department Prevention and Evaluation, Leibniz Institute for Prevention Research and Epidemiology – BIPS, Achterstr. 30, 28359, Bremen, Germany
[2]Center for Social Policy Research, University of Bremen, Mary-Somerville-Str. 5, 28359 Bremen, Germany
Full list of author information is available at the end of the article

been identified as particularly at risk [9-12]. It has been argued that populations residing in urban centers are more vulnerable to heat events due to the urban heat island effect and higher population density [13-17]. In recent years additional concerns have arisen about a contribution of global warming to an increased frequency of extreme temperature events [18,19]. "Business as usual" climate change scenarios estimate that the incidence of heat events is likely to increase in the near future [20,21]. As a result, it has been suggested that future health risks from heat might increase [22-24]. In 2012, extreme temperature events classified as disasters by the WHO Collaborating Centre for Research on the Epidemiology of Disasters - CRED occurred 51 times worldwide, giving climatological disasters (temperature events, droughts and wildfires) an overall share of 23.8% of all 2012 disasters [25]. Recent severe heat waves occurred in Europe and Russia in 2003, 2006 and 2010, in the United States in 2012, in Australia in 2009 and 2013, and in Japan in 2010 and 2013, among others [26,27]. Beyond these extreme cases, smaller scale heat waves occur frequently and pose risks to human health. Heat impacts on humans can be measured through thermal indices [28]. Various methods to calculate a heat index exist, and without adherence to a standard, comparability between measurements and studies is challenging [29,30].

With a changing climate, populations of large cities in temperate regions, subtropical or tropical climates have all been characterized as vulnerable to heat [3,31,32]. Further measures may be needed to continually protect human health from adverse effects of heat on all continents. Adaptation to climate change has been defined as a "process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" [33]. In this study, we are particularly interested in intentional, planned adaptation.

While we have conflicting information on risk perception of heat among populations [11,34,35], older persons have been characterized as especially susceptible to ill effects of heat [36-38]. Heat warning systems have been introduced as a prevention measure [39-41]. These usually combine information from weather stations based on a cutoff system with more or less targeted communication campaigns. Such heat warning systems can now be found across the planet, usually at city level [42].

Despite increased interest in climate change and its impacts, and a large number of heat prevention plans in place in higher-income countries to protect human health [39,43], we have hardly any conclusive evidence on the effects of said adaptation measures [44]. Is climate change adaptation to heat reducing heat stroke incidence and heat-related mortality? This study uses a systematic review design in an attempt to answer this question.

Methods

We conducted a systematic literature review of peer-reviewed published literature. The PRISMA checklist, research protocol and the data extraction sheet can be found in the supplementary material (Additional files 1, 2 and 3). The scope of our review was as follows:

Population: urban populations of all ages, sexes and ethnic groups.

Intervention: Heat adaptation measures conducted in an urban area.

Because heat adaptation aims at preventing adverse health effects, we use the terms heat adaptation and heat prevention interchangeably in this review.

Comparison: none (no adaptation).

Outcomes: impacts on heat-related morbidity and mortality.

Context: International large urban centers[a].

The following outcomes were of interest:

- Impacts measured as reduction in excess heat stroke incidence, hospitalization for heat-related illness, and cases of cardiovascular, respiratory and all-cause mortality in extreme heat periods as compared to previous heat periods.
- Effectiveness measured
  1) as reduction in excess heat stroke incidence, hospitalization for heat-related illness and cases of cardiovascular, respiratory and all-cause mortality, for which we accepted the proxy indicator of health services use (emergency medical care at facility or on ambulance; hospital release diagnosis or physician's diagnosis) for heat stroke,
  2) as heat island exposure reduction signaled through changes in urban planning or taking up of heat warning systems.

Search strategy

We applied a combined search strategy of automated search and hand search of journals. Two researchers independently searched the electronic databases PubMed, Web of Knowledge, Biological Abstracts, CAB Abstracts and ProQuest Dissertation & Theses A&I.

We applied combinations of the search terms climat*, heat, adapt*, compounds of climate change, adaptation, adapting, heat wave, extreme heat, heat island combined with evaluat*, effect* and exposure in the automated searches[b].

Search strings had been pre-tested during a mapping review.

Additionally, both researchers manually searched the journals Climatic Change and International Journal of Climate Change Strategies and Management to increase our chances of finding articles that focus on evaluating

adaptation strategies from a management or urban planning perspective.

Ancillary search procedures included checking the reference lists of identified primary studies as well as asking three leading international researchers for suggestions and works in progress.

Selection criteria

The following inclusion and exclusion criteria were applied:

Inclusion

Must include adaptation specifically for heat. All languages as long as an English abstract is available. Only reviews and original research articles as well as books or published national and international reports (defined as having an ISBN number). Must include at least one human health outcome, or health-related behavior changes. Must contain an evaluation or assessment. All publication years included.

Exclusion

No English abstract available. Comments, editorials, correspondences and letters are excluded. Mitigation rather than adaptation focus of the article. Focus too limited: only a description of heat adaptation planned or implemented without assessment of effects. No evaluation of human health impacts.

Two researchers independently selected relevant articles from the searches with the same search terms as well as through cross-checking reference lists. One researcher contacted leading experts for input on work-in-progress and further studies to be included via email.

Any disagreement between the two researchers was resolved and evaluated by a third member of the research team.

Study quality assessment

For study quality assessment, the NHS Critical Appraisal Skills Program (CASP) [45] checklists were used according to each study type. CASP also provides a checklist for quality appraisal of qualitative studies. Although specific tools for each study type prohibit a general comparison across study types, Katrak et al. [46] have previously criticized generic assessment tools for being too general. In addition, our review aimed at being comprehensive and therefore intentionally included a vast range of studies. Any attempt to assess these with a generic tool was unfit for representing their diversity. The CASP checklists were aimed at answering general guiding questions also provided by Booth et al. [47]:

1. Validity: Do the results of a study fit with other available evidence? How are confounding and bias handled?
2. Reliability: What are the results and how much might they be owed to chance?
3. Applicability: Can we generalize the results? How strong are recommendations for practice based on these study results?

For the specific questions, see Additional file 4.

To reduce the risk of subjective quality judgment, we decided not to exclude nor weigh studies based on quality rating or scales. While study quality assessment is important to judge the overall evidence base for adaptation effectiveness, the usefulness of excluding studies based on quality has been contested [47,48].

Study synthesis

Due to the heterogeneity and varied designs of studies and reports, no overall quantitative meta-analysis could be performed. Instead, we applied narrative synthesis.

We conducted two subgroup analyses of survey studies and observational studies as these were the two most common study types.

Results

The database search led to 5539 results, 2299 after removal of duplicates. After title and abstract screening 2252 articles were excluded because they did not concern human health or did not contain an evaluation. 47 articles were assessed as full texts. We excluded 29 articles after reading the full texts because no evaluation according to our criteria was described. Through additional sources such as reference lists we identified 12 studies. All in all, 30 articles were included in the review, as shown in the PRISMA flowchart (Figure 1).

Study characteristics

Of the 30 articles, 12 were studies conducted in European countries [35,49-59], 10 studies were from the United States, one of which included a Canadian study city [34,60-68], two from East Asian countries [69,70], one from Canada [71], and one from Australia [72]. The systematic reviews were not restricted to any continent [73-76]. Figure 2 shows the imbalance of country of origin for the publications in a distorted cartogram [77]: more studies were published in higher-income, Western countries versus lower-income countries. Countries with a higher output are represented as larger in the cartogram (Figure 2). We did not identify any studies from Africa, Southeast Asia or Central and South America. The Pacific Region was also underrepresented.

Time of publication ranged from 1992 to 2013 (median = 2008). Regarding study population, about one-third of the studies focused on older persons (n = 11) [35,49,50,52,57-59,61,66,67,69]. However, definitions of an

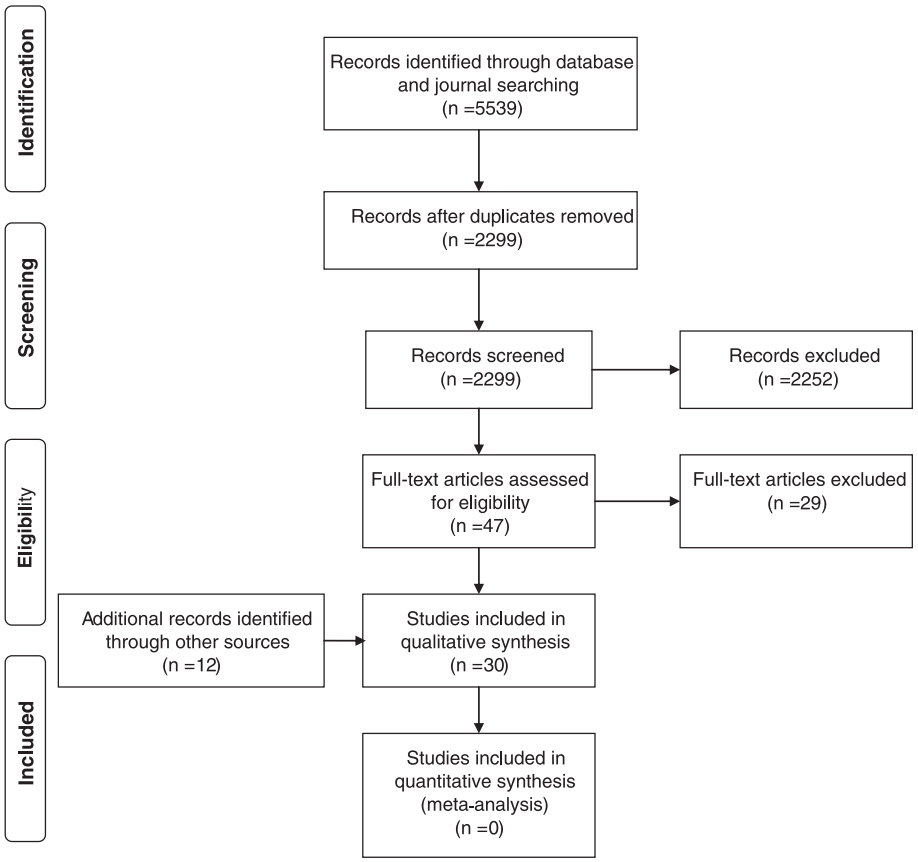


Figure 1 PRISMA flowchart of study selection process.

older person differed and ranged from inclusion of over 64 to 75 and beyond. The remaining studies included all adults aged 18 years and older.

Half of the identified studies were observational studies with regression as main analysis method (n = 16) [49,51-53,55,56,58-60,63-65,67-70], followed by survey research (n = 6) [34,54,62,66,71,72]. We identified two qualitative interview studies [35,50], one randomized controlled trial (RCT) [57], one economic analysis [61], and four systematic reviews [73-76]. Additional file 5 describes characteristics of the studies included in the review.

Figure 2 Continents of study origin. Distorted cartogram of continents of study origin, weighted by number of studies per country. Countries with higher number of publications are larger in the cartogram.

Heat adaptation

Adaptation options to heat assessed in the included studies ranged from heat warning campaign communication [35,49,50], use of fans [75], and active surveillance programs [57] to biological acclimatization over decades [55,56] (Figure 3).

Main outcomes were mortality rate trends over several years, mortality rates pre- and post-intervention, and changes in awareness or behavior over time. Due to limited comparability of the studies, specific study results will be discussed under subgroup analysis for regression analysis and perception survey results (Tables 1 and 2).

Quality appraisal

We used the CASP checklists [45] to assess study quality. As expected from scoping literature searches, studies included in the review were highly heterogeneous in research question and design. We used the CASP checklists for RCT (n = 1) [57], systematic reviews (n = 4) [73-76], qualitative studies, also used for survey research (n = 7) [34,35,50,54,66,71,72], case–control studies including one survey-based case–control study (n = 15) [51-53,55,58-60,62-64,67-70,78], economic analyses (n = 1) [61] and cohort studies (n = 2) [49,65]. Results of the quality appraisal are presented in Additional file 4. Although we did not assign a quality score, we were able to see two main challenges for research design in the studies that may compromise quality: for survey and qualitative research on awareness changes, no baseline assessment was performed. For regression analyses, the definition of a control was not standardized.

Subgroup analysis: articles comparing mortality and morbidity

The majority of articles (n = 17) compared mortality or morbidity, either over a period of several years or before and after implementation of a heat wave warning system. Study types in this assessment included one RCT [57], 14 case–control studies [51-53,55,58,59,63,64,67-70,78,79] and 2 cohort studies [49,65]. However, the variety of outcomes reported prevented us from combining results in a meta-analysis (Figure 4).

Outcomes were reported as odds ratios, mortality rates, excess deaths, relative risk, increased percentage of mortality per centigrade temperature increase, or as a mortality index. Table 1 shows results of these studies. The studies were of high quality using standard epidemiological methods. Overall, the majority of assessments report a reduction of adverse effects during extreme heat. This applies both to longitudinal and short-term studies. For instance, Chau et al. [69] report an increase of 1.23 deaths from ischemic heart disease in Hong Kong where a heat warning system was absent between 1997 and 2005. For the cities in the United States, on the other hand, Davis et al. [60] find an increased heat-related mortality rate since 1964 for Atlanta, Buffalo, Dallas, Denver, Seattle and San Francisco. In Central Europe, Kysely and Plavcova [78] describe an overall decrease in mortality by 10% from 1986 to 2009. A common challenge for the studies is linking the decrease to specific adaptation measures: alternative hypotheses for the observed declines in sensitivity have not been tested.

Subgroup analysis: perception and behavior change studies

The second largest group of study types was comprised of awareness and perception surveys and interviews. The

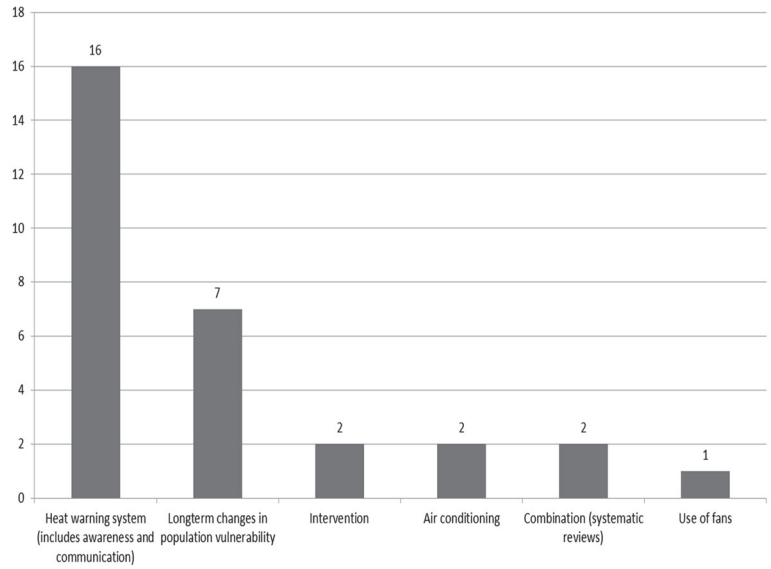


Figure 3 Type of adaptation in studies included in review. Adaptation measures discussed in the individual studies.

Table 1 Results of the regression analysis studies and RCT

Reference	*Type of evaluation*	*Results*
Rogot et al. 1992 [65]	Comparing mortality during heat in people with air conditioned homes to those with no air conditioning	Central air condition compared to no air condition: OR below 1 for all groups, significant (p = 0.03 Mantel-Haenszel). **Room air condition compared to no air condition: OR 0.96 for total group, p = 0.71). RR for central air condition vs. no air condition 0.58 for total group,** RR for room air condition to no air condition 0.41 for total group
Smoyer 1998 [67]	Comparing mortality rates of 1980 and 1995	The average elderly **mortality rate on heat wave days** went down **from 2.36 (SD 1.20) to 1.65 (SD 0.52)**, the average elderly mortality rate on non- heat days went down from 1.56 (SD 0.45) to 1.46 (SD 0.55)
Palecki et al. 2001 [64]	Comparing excess deaths in 1995 and 1999	**Mortality rates in Chicago and St Louis both 1.4 per 100.000 in 1999,** if not using core cities but counties. In 1995, 700 died in Chicago and 27 in St Louis
Weisskopf et al. 2002 [68]	Changes in population vulnerability	Model 1: predicted mortality rate of 1.80 per heat-index degree above 80 °F. 42.3 expected deaths, actual deaths in 1999 were 10. Model 2: **RR** for heat-related death in 1999: **0.17-0.24, RR** for emergency medical services in 1999 **0.32-0.46**
Davis et al. 2003 [60]	Comparing temperature mortality relationship from 1964 to 1998	The threshold for 1960s-1970s is no longer connected to an increased mortality in the 1980s in Northeastern cities, and in the 1990s 10 show no elevated mortality above threshold and of the remaining 18 cities 12 show a decline in mortality rate. **Six cities** remain with an **increased mortality rate** above the threshold: Atlanta, Buffalo, Dallas, Denver, Seattle, San Francisco
Delaroziere and Sanmarco 2004 [52]	Comparing mortality before and after implementation of warning system	Mean **index of daily excess mortality** has dropped from 3.27 in the years 1986 to 1982, **down to 1.32** in the years 1984–1997, p = 0.008)
Marinacci et al. 2009 [57]	Comparing no. of hospitalizations and deaths in summer 2004, RCT	Males: in intervention group Odds to be emergency hospitalized: **OR 0.33, 95% CI: 0.11; 0.96.** Females: in intervention group odds to be hospitalized overall: **OR 0.96, 95% CI: 0.93; 0.98**
Tan et al. 2007 [70]	Comparing daily excess mortality in 1998 and 2003.	**Correlation coefficient** between daily deaths and weather and air pollution parameters: death and time of heat wave: **0.34 in 1998 and 0.41 in 2003,** Tmax in 1998 0.51 to 0.62 in 2003. Heat related deaths in 1998: 358 (absolutes), 253 in 2003 (absolutes)
De'Donato et al. 2008 [51]	Daily excess mortality before (reference period) and after implementation of heat warning system	J-shape temperature-mortality curve in all cities. In Milan and Rome in 2007 there was a weaker association between high temps and mortality. In Bari and Catania there was a greater impact of high temp on mortality in 2007 (all compared to 2003). In 2007 excess mortality occurred during three heat waves, with **impacts on mortality of +10-41% in the center and 11-56% in the South**
Fouillet et al. 2008 [53]	Comparing excess daily mortality in 2003 to 2006	During summers 2004 and 2005, observed no. of deaths was 2-8% lower than predicted no. of deaths. In 2006 2065 excess deaths occurred, predicted for that temperature were 6452 excess deaths, **4400 fewer deaths than predicted**
Kysely and Kriz 2008 [55]	Comparing excess mortality in the 1990s and 2003	Excess daily mortality in 1990s: 98 deaths in 1992, 113 deaths in 1994; 50 deaths in 2003. Aggregated: 1992 718 excess deaths, in 1994 919 excess deaths, in 2003 **236 excess deaths**
Bargagli et al. 2009 [49]	Mortality rate among patients with active surveillance and those without = comparison of mortality rate with and without intervention	**Excess mortality on heat days vs. non-heat days in controls: RR 1.20, 95% CI: 1.14-1.27**; excess mortality on heat days vs. non-heat days in **intervention patients: RR 0.95, 95% CI: 0.65-1.34**
Chau et al. 2009 [69]	Comparing associations between hot weather warning and mortality rates from ischemic heart disease and stroke from 1997 to 2005.	Absence of warning system was associated with an increase of **1.23 deaths** from IHD (95% CI 0.32; 2.14), an increase of **0.97 deaths** from stroke (95% CI: 0.02; 1.92) per day
Ostro et al. 2010 [63]	Comparing hospitalization among those with air conditioning to those without	Reduction in excess risk of hospitalization with 10% increase in A/C ownership: respiratory disease: **relative reduction 19.9% (95% CI 0.7;39.), CVD relative reduction: 49.1% (95% CI 19.9;78.3), heat stroke relative reduction 4.0% (95% CI 1.9;6.0)**
Kysely and Plavcova 2012 [78]	Comparing temperature mortality relationship from 1986 to 2009	Significant **trends in deviation of mortality on lag days from 1986 to 2009: all ages D + 1 -0.61, D + 2 -0.55; 70- years: D + 1 -0.66; 70+ years: D + 2 -0.66.** Relative deviations of mortality

Table 1 Results of the regression analysis studies and RCT *(Continued)*

		declined by 0.4% to 0.5% in all age groups until 2009. **Overall decline of mortality by 10% for all groups**
Morabito et al. 2012 [58]	Comparing mortality before and after implementation of warning system	Odds Ratios for mortality by age group pre- and post-2003: only significant in 75 years+, OR for average apparent temperature before 2003 **1.18 (CI 1.10-1.26),** 2004 to 2005: **1.24 (CI 1.14-1.35)**, 2006–2007: **1.20 (CI 1.09-1.31).** Also significant for maximum temperature
Schifano et al. 2012 [59]	Comparing daily mortality in 1998–2002 (before) and from 2006 to 2010 (after) implementation of prevention program	**Weaker relationships between heat and mortality in all 16 cities post-intervention.** Percentage change in mortality per 3°C increase in max apparent temperature MAT (pooled results): for 0 to 3% increase of 3°C increase: 1998–2002: 5.65%, for 2006 to 2010: 5.65%; 3 to 6% MAT increase: in 1998–2002 6.72% change, in 2006 to 2010: 7.79% change. Largest results: **12 to 15% MAT increase, 41.76% change from 1998–2002; 5.65% change from 2006 to 2010**

Main results are in bold.

articles all shared a common definition of awareness and behavior change. No pre-test was conducted in the survey and interview studies except for the study by Mattern et al. [62]. Results are presented in Table 2.

Most participants were informed of risks of extreme heat through media, television being the most common [34,54,66,71,72]. Individual adaptation behaviors were use of air condition, drinking water and avoiding strenuous activities [34,35,50,54,66,71,72]. Risk perception was discussed in the publications by Abrahamson et al. [35] and Bittner and Stößel [50]: both discovered that among their participants, older persons did not feel more at risk than younger populations. Concern about the costs of increased air condition use was mentioned by Sheridan [66]. We argue that due to the lack of pretests, the success of behavioral intervention advice cannot be estimated conclusively as it cannot be compared to knowledge and behavioral habits prior to the implementation of an adaptation measure.

Discussion

The results of our review reveal difficulties in assessing adaptation effectiveness and are consistent with previous research. This suggests that issues of methodological rigor and what to measure when speaking about effectiveness of heat adaptation have not yet been resolved, despite increased interest in the matter.

Common themes in all studies were difficulties assessing adaptation effectiveness with standard epidemiological methods. This has been discussed particularly in the four systematic reviews. Specifically, the following issues in conducting rigorous studies to generate conclusive evidence of adaptation effects have been named:

- Differing heat wave impacts due to unstable intensity and frequency [76].
- Role of confounders such as socio-economic variables and long-term healthcare improvements [76].
- Short time frame between implementation of heat prevention and evaluation [73].
- Location-specific acclimatization [73].
- Simultaneous implementation of sub-interventions in a heat prevention plan [73].
- Data availability [76].

Gupta et al. [75] call for experimental study designs to assess the effectiveness of using fans during a heat wave as they were unable to resolve conflicting information from observational studies in their Cochrane review. In our included studies a call for more rigorous methods was the standard solution to the above mentioned issues, without specific recommendations on how to achieve this. When trying to judge whether the information we gathered through the review is sufficient proof that heat adaptation reduces heat-related mortality and illness, we struggle with the following problems posed by the available studies:

- Although older persons are generally included as a vulnerable group, age ranges differ and impede comparability.
- Lack of pre-tests in awareness studies. Participants' knowledge of heat warning systems or healthy behaviors cannot clearly be attributed to the adaptation.
- Most of the observational studies did not examine alternative hypotheses for changes. Often authors mentioned a variety of reasons for changes, all of them with equal or unknown likeliness.

Why is conducting experimental research of adaptation to heat so difficult? For one, defining the counterfactual, i.e. what would have happened in the absence of the adaptation measure, is problematic, because usually an entire city or even country is exposed to the adaptation measure. Choosing a different city as control would

Table 2 Results of reviews, survey studies qualitative interview studies and economic analysis

Reference	*Type of evaluation*	*Methods*	*Results*
Mattern et al. 2000 [62]	Case-only survey	Standardized questionnaire	34 respondents. At pretest 67% of respondents knew whom to contact during heat for assistance, post-intervention 94% knew whom to contact. 6% knew about the City of Philadelphia hotline at pretest, 29% at post-test. **76% monitored temperature daily,** 21% monitored temperature during hot days
Ebi et al. 2004 [61]	Economic cost-effectiveness evaluation	Multiple linear regression, estimation of lives saved, estimation of benefits	**2.6 lives saved** on average for each warning day plus three day lag (not significant). Estimated value of $6.12mill. per life = **$468 mill. saved with 117 lives saved over 3 years.** Costs for system $210.000
Kishonti et al. 2006 [54]	State of knowledge on heat, the warning system, protective behavior	Quantitative telephone survey	Sample size 2500. Awareness of heat: persons between 30 and 59 years of age mentioned at least two health impacts of heat. 27% of respondents saw hypertension as risk, 11% heat stroke, 22% CVD. **25% of interviewees had seen the communication campaign**, of whom 78% saw it on TV, 57% in the newspaper and 41% on the street. **59% of respondents had heard of heat alarm**
Bouchama et al. 2007 [74]	Systematic review and meta-analysis on risk and protective factors for heat-related deaths	Systematic review and meta-analysis	Protective factors: home air condition **(OR 0.23 95% CI 0.1-0.6)**, visiting cool environments **(OR 0.34 95% CI 0.2-0.5)**, increased social contact **(OR 0.40 95% CI 0.2-0.8)**, taking extra showers **(OR 0.32, 95% CI 01.-1.1)**, use of fans **(OR 0.60 95% CI 0.4-1.1)**
Kalkstein and Sheridan 2007 [34]	State of knowledge on heat, the warning system, protective behavior	Quantitative survey	201 respondents, 14 of age 65+. 90.2% of females knew about the heat warning system, 75.3% of males knew about the system. 25% felt heat was dangerous. Of those aware of heat warnings, **49.7% altered behavior**, 47.3% did not
Sheridan 2007 [66]	State of knowledge on heat, protective behavior, available cooling systems in the house	Quantitative telephone survey	908 respondents across all cities. In the four cities, **most people learned about heat warnings on television** (Dayton: 89%, Philadelphia: 84%, Phoenix: 92%, Toronto: 64%). **46% of respondents altered their behavior during heat**, varying significantly across cities ($p = 0.003$). Use of air conditioning self-restricted due to concerns about costs
Abrahamson et al. 2009 [35]	State of knowledge on heat-related health risks and protective behavior	Semi-structured interviews with topic guide, 1 data collection wave summer of 2007	73 respondents, mean age 81 years (range 72–90) in London; mean age 80 (range 75 to 94) in Norwich. Themes identified: perception of vulnerability to heat; behavior change during heat; knowledge of protection measures; perception of usefulness of heat wave plan. **No consensus on usefulness of heat wave plan components**. Most respondents adjust their behavior during heat. Few respondents perceived of themselves at risk
Kosatsky et al. 2009 [71]	State of knowledge on heat, protective behavior	Quantitative, questionnaire based face-to-face interviews	238 respondents. 86% know about risks of high night time temperature, 94% know about health risks for lung and heart disease patients. 80% listen to weather forecasts, mid-summer **93% had heard a heat advisory**. 71% use a fan, 87% do less strenuous activities in heat. 73% have air condition at home, those with air condition reported more additional behavior changes than those without
Bassil and Cole 2010 [73]	Systematic review of all study types	Systematic review and expert elicitation	Narrative results: **most studies evaluate heat warning systems, awareness and perception.** If effects measured then often as regression analysis. Methodological challenges
Oakman et al. 2010 [72]	State of knowledge on heat, heat warnings, protective behavior	Quantitative telephone survey	328 interviews, **63% knew of health warnings**: of these 74% saw it on TV, 42% on radio, 15% in newspapers. 96.1% of respondents used air condition in hot weather, 94% drank water, 90% stayed indoors
Bittner and Stößel 2012 [50]	State of knowledge on heat, protective behavior, heat warnings	Questionnaire-based interviews, qualitative analysis with framework approach	20 respondents. Themes: vulnerability, changes in daily routine, sources of information, content of advice received, activity level and health status. **Individual vulnerability not always perceived.** Controversial role of the GP. 19 respondents stated they changed behavior
Gupta et al. 2012 [75]	Systematic review of RCTs, and experimental designs with controls	Systematic review according to Cochrane guidelines	**No studies with rigorous experimental designs found**

Table 2 Results of reviews, survey studies qualitative interview studies and economic analysis *(Continued)*

Toloo et al. 2013 [44]	Systematic review of any heat warning evaluation	Systematic review of databases	Six articles asserted that post-intervention expected deaths were reduced. **High study heterogeneity.** One economic assessment. Eight studies assessed awareness, including one qualitative study

Main results are in bold.

require careful matching. This is difficult for many reasons: for example, intercity microclimate variability could bias results, and to assess effects the control city would need to be exposed to a heat event of similar magnitude and length. Unlike other public health interventions, researchers and practitioners cannot limit exposure; they can only mediate it.

Second, heat prevention can occur at structural level, or at individual level through behavior change. Ethical concerns could be raised if structural prevention or a warning system were only available to an intervention group in one city. For instance, control populations could not be prevented from accessing public green spaces.

Third, heat by itself is not a new phenomenon. Much of the heat-related health advice provided by risk communication campaigns is common sense information: to stay hydrated, for example, or to seek shade and cool places [80]. Physical discomfort during heat makes it likely that people have followed such advice before official warnings were even issued. This might not only suggest absence of the classic control group for behavior, it is also more difficult to compare knowledge pre- and post-information campaigns. In light of future population aging, potential improvements to adaptation effects lie with targeting those elderly people who do not feel at risk through awareness raising interventions despite these difficulties. The use of innovative materials and social norms approaches could be evaluated.

While we argue that concrete evidence for the effectiveness of specific planned adaptation measures is lacking, our results show a mostly unanimous decline in sensitivity to heat over longer time periods. Alternative hypotheses for the causes of this decline should be investigated. Proposed alternatives have included biological adaptation [81], improvements to healthcare systems [82], technological advancements [83], adjustments to the urban built environment [84], and social progress [84]. The role each of the alternatives plays in declining heat sensitivity is debated [78].

Aware of these shortcomings, recent research projects into methods specifically for adaptation assessments have been designed [85], results are not yet available.

We were surprised to be unable to identify articles assessing infrastructural measures such as greening, or supply of air conditioning, although we had specifically intended to include these. Our focus on human health and our health–related search terms may have prevented us from finding articles on urban planning effects. Connecting specific urban planning to public health assessments might be a challenging but interesting future research topic.

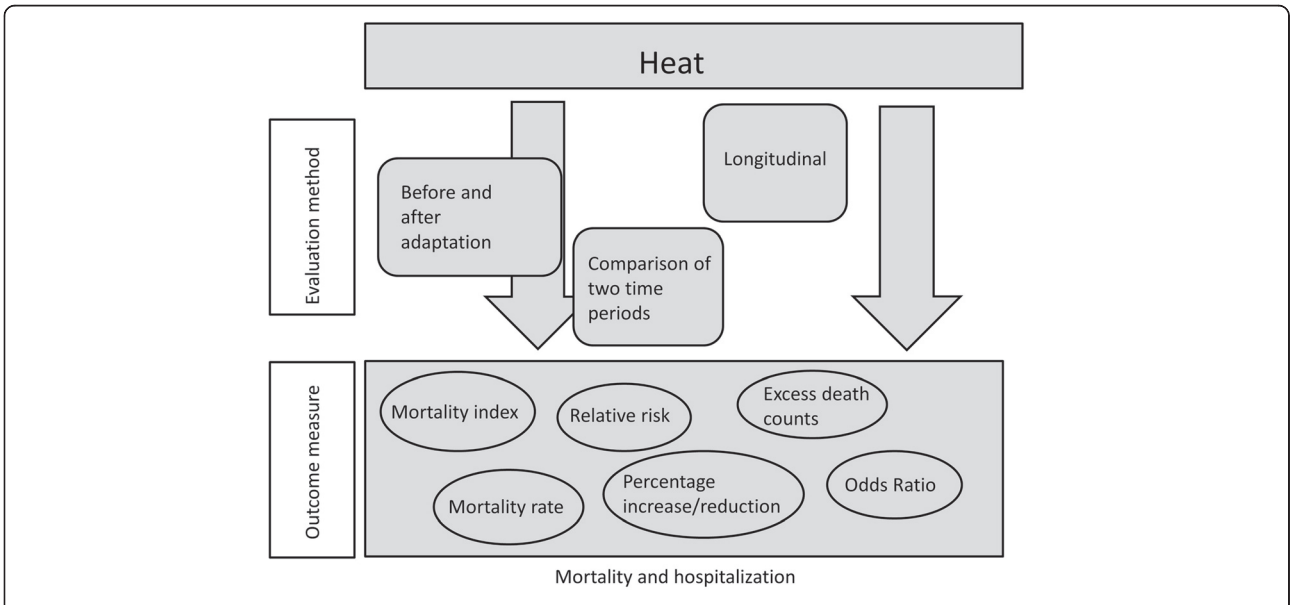


Figure 4 Model of the variability in reported outcomes.

Policy implications

With such little conclusive evidence of effectiveness, recommendations for future action need to be carefully considered. On the one hand, policymakers may feel a moral imperative to act regardless of the evidence base. On the other hand, negative health effects of the adaptation measures themselves should be avoided. Possible risks from adaptation include misinformation on protective behaviors leading to maladaptation, or increased allergic disease incidence through greening of urban spaces [86]. Using "low-regret" adaptation measures could be an interim solution until more suitable assessment methods have been developed. In climate change adaptation, low-regret options are generally all strategies that either offer more than one benefit or keep options for amendments open [87,88]. Such options have been described as useful when uncertainties are large, as they do not rely on exact climate change projections [88,89]. They yield a number of benefits for a system's capacities to deal with climatic changes while only requiring moderate input, and are less likely to have negative effects [87,88]. In practice, benefits will have to be weighed against opportunity costs and trade-offs [90].

Examples for popular low-regret options in heat adaptation might be urban greening and heat wave warnings [91]. However, creating such an inventory of low-regret measures does not actually solve the issue of whether adaptation works. A prominent voice in climate change and health research, Anthony McMichael, argued that a focus on traditional epidemiological assessments methods may not lead to increased knowledge as desired [92]. Instead, McMichael wrote, taking risks with new concepts, methods and interdisciplinary approaches to research are required [92].

Limitations

In this review, we focused on peer-reviewed literature and excluded all unpublished or grey literature directing main attention towards database searches. This was justified by our specified interest in evidence of effectiveness as proven by rigorous scientific research, rather than in any evaluation possibly conducted by practitioners. A previous review from 2010 [73] stated that grey literature would be a more likely source of effectiveness information than peer-reviewed journal articles owing to the low number of evaluations conducted in research. Nonetheless, Bassil and Cole [73,93] only found one unpublished study that contributed to the information on effects. As there is no legal imperative for policymakers in Europe to evaluate adaptation strategies, for example, few assessments are undertaken [94]. We aimed for comprehensiveness and therefore included non-health related databases to search for infrastructural evaluations. The final article selection, however, was entirely from academic health and medicine journals. This suggests that even if evaluation of green spaces or other infrastructural measures occur, these evaluations are less likely to consider co-effects on human health.

We identified no articles from Africa, Southeast Asia, the Pacific or Central and South America. This confirms previous findings on a dominance of high-income Western countries in adaptation research [95].

Nevertheless, we were able to identify 30 articles dealing with issues of evaluating heat adaptation, a large number in light of the novelty of adaptation and evaluation research. By our subgroup analysis approach, we contributed to knowledge on effectiveness as generated by two current adaptation evaluation standards: awareness surveys and mortality rate comparisons. Our review identifies major challenges to evaluation and proposes further research into the potential of adaptation measures for health protection from extreme heat.

Conclusions

Our results show that rigorous evaluation of adaptation is rare and difficult to conduct. The potential health effects of adaptation can currently not be measured conclusively. Up to now, we find limited intersectoral efforts between public health agencies and climate change adaptation policy. Such efforts might contribute to a reduction in adverse health effects of heat. In addition, involvement of the health sector in adaptation design, implementation and evaluation might increase chances of successful adaptation.

Current knowledge does not prove effectiveness of planned adaptation, yet a decline in sensitivity to heat hints at important developments. Recent articles published after the search period for this review observe a similar decline over long time periods [96-98]. Whether biological adaptation, continuous improvements in healthcare, changes to the urban environment not declared "adaptation," or a different unknown reason caused said decline is a matter of further interest. The seeming paradox between the observed decline in the examined studies and scholarly works referring to an expected increase in heat-related adverse health effects [99] needs to be assessed further as well. Low-regret adaptation options might be investigated while simultaneously increasing efforts to overcome methodological evaluation challenges with further research.

Endnotes

[a]Originally we had planned to include only cities with more than 500,000 inhabitants. Due to the limited study availability, however, we decided to broaden this criterion to cities of any size.

[b]* = wildcard, all possible word endings included.

Additional files

Additional file 1: PRISMA checklist.

Additional file 2: Review protocol. The protocol for the systematic review.

Additional file 3: Data extraction sheet.

Additional file 4: Quality appraisal results. The results of the quality appraisal conducted with CASP checklists.

Additional file 5: Table of characteristics of studies included in review. Studies are presented ordered by type and year of publication.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MB conceptualized the study, conducted the literature search, study quality appraisal and data analysis, and wrote the article. IR conducted the literature search, study quality appraisal during the data extraction stage, and participated in writing the draft. Both authors read and approved the final version of this manuscript.

Acknowledgements

MB was supported by a Leibniz Institute for Prevention Research and Epidemiology – BIPS and University of Bremen joint dissertation scholarship. The authors thank Prof. Hajo Zeeb for support throughout the study and for helpful comments on the manuscript, as well as Berit Steenbock and Edda Hein for critical reading of the article drafts. MB would like to thank Michael Lehmann for an introduction to the program ScapeToad for cartograms. Both authors thank the three reviewers for their thoughtful comments that helped improve the manuscript.

Author details

[1]Department Prevention and Evaluation, Leibniz Institute for Prevention Research and Epidemiology – BIPS, Achterstr. 30, 28359, Bremen, Germany. [2]Center for Social Policy Research, University of Bremen, Mary-Somerville-Str. 5, 28359 Bremen, Germany. [3]Medical University Hannover, Carl-Neuberg-Str 1, 30625 Hannover, Germany.

Received: 2 May 2014 Accepted: 25 September 2014
Published: 28 October 2014

References

1. Baccini M, Kosatsky T, Analitis A, Anderson HR, D'Ovidio M, Menne B, Michelozzi P, Biggeri A, the PHEWE Collaborative Group: **Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios.** *J Epidemiol Community Health* 2011, **65:**64–70.
2. Ng CFS, Ueda K, Ono M, Nitta H, Takami A: **Characterizing the effect of summer temperature on heatstroke-related emergency ambulance dispatches in the Kanto area of Japan.** *Int J Biometeorol* 2014, **58:**941–948.
3. McMichael AJ, Wilkinson P, Kovats RS, Pattenden S, Hajat S, Armstrong B, Vajanapoom N, Niciu EM, Mahomed H, Kingkeow C, Kosnik M, O'Neill MS, Romieu I, Ramirez-Aguilar M, Barreto ML, Gouveia N, Nikiforov B: **International study of temperature, heat and urban mortality: the "ISOTHURM" project.** *Int J Epidemiol* 2008, **37:**1121–1131.
4. **Heatstroke information.** http://www.fdma.go.jp/neuter/topics/houdou/h25/2510/251015_1houdou/01_houdoushiryou.pdf.
5. Fowler DR, Mitchell CS, Brown A, Pollock T, Bratka LA, Paulson J, Noller AC, Mauskapf R, Oscanyan K, Vaidyanathan A, Wolkin A, Taylor EV, Radcliffe R: **Heat-related deaths after an extreme heat event — Four States, 2012, and United States, 1999–2009.** *Morb Mortal Wkly Rep* 2013, **62:**433–436.
6. Yeo TP: **Heat stroke: a comprehensive review.** *AACN Clin Issues Adv Pract Acute Crit Care* 2004, **15:**280–293.
7. Bouchama A, Knochel JP: **Heat stroke.** *N Engl J Med* 2002, **346:**1978–1988.
8. Atha WF: **Heat-related illness.** *Emerg Med Clin North Am* 2013, **31:**1097–1108.
9. Martinez M, Devenport L, Saussy J, Martinez J: **Drug-associated heat stroke.** *South Med J* 2002, **95:**799–802.
10. Green H, Gilbert J, James R, Byard RW: **An analysis of factors contributing to a series of deaths caused by exposure to high environmental temperatures.** *Am J Forensic Med Pathol* 2001, **22:**196–199.
11. Wolf J, Adger WN, Lorenzoni I, Abrahamson V, Raine R: **Social capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities.** *Glob Environ Chang* 2010, **20:**44–52.
12. Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O: **Heat stress in older individuals and patients with common chronic diseases.** *CMAJ* 2010, **182:**1053–1060.
13. Rosenthal JK: *Evaluating the Impact of the Urban Heat Island on Public Health: Spatial and Social Determinants of Heat-Related Mortality in New York City.* New York City: Columbia University; 2010.
14. Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P: **The impact of heat islands on mortality in Paris during the August 2003 heat wave.** *Environ Health Perspect* 2012, **120:**254–259.
15. Tan J, Zheng Y, Tang X, Guo C, Li L, Song G, Zhen X, Yuan D, Kalkstein AJ, Li F: **The urban heat island and its impact on heat waves and human health in Shanghai.** *Int J Biometeorol* 2010, **54:**75–84.
16. Stone B, Hess JJ, Frumkin H: **Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities?** *Environ Health Perspect* 2010, **118:**1425–1428.
17. Oikonomou E, Davies M, Mavrogianni A, Biddulph P, Wilkinson P, Kolokotroni M: **Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London.** *Build Environ* 2012, **57:**223–238.
18. IPCC: **Summary for Policymakers.** In *Clim Chang 2007 Impacts, Adapt Vulnerability Contrib Work Gr II to Fourth Assess Rep Intergov Panel Clim Chang.* Edited by Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE. Cambridge: Cambridge University Press; 2007:7–22.
19. IPCC: **Summary for policymakers.** In *Clim Chang 2007 Phys Sci Basis Contrib Work Gr I to Fourth Assess Rep Intergov Panel Clim Chang.* Edited by Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL. Cambridge [u.a.]: Cambridge University Press; 2007:1–18.
20. Greene S, Kalkstein LS, Mills DM, Samenow J: **An examination of climate change on extreme heat events and climate–mortality relationships in large U.S. cities.** *Weather Clim Soc* 2011, **3:**281–292.
21. Huang C, Barnett AG, Wang X, Vaneckova P, FitzGerald G, Tong S: **Projecting future heat-related mortality under climate change scenarios: a systematic review.** *Environ Health Perspect* 2011, **119:**1681–1690.
22. Hajat S, Vardoulakis S, Heaviside C, Eggen B: **Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s.** *J Epidemiol Community Heal* 2014, **68**(7):641–648.
23. Knowlton K, Lynn B, Goldberg RA, Rosenzweig C, Hogrefe C, Rosenthal JK, Kinney PL: **Projecting heat-related mortality impacts under a changing climate in the New York City region.** *Am J Public Health* 2007, **97:**2028–2034.
24. Morabito M, Crisci A, Moriondo M, Profili F, Francesconi P, Trombi G, Bindi M, Gensini GF, Orlandini S: **Air temperature-related human health outcomes: current impact and estimations of future risks in Central Italy.** *Sci Total Environ* 2012, **441:**28–40.
25. Guha-Sapir D, Hoyois P, Below R: *Annual Disaster Statistical Review 2012: The Numbers and Trends.* Brussels: Centre for Research on the Epidemiology of Disasters (CRED) and Institute of Health and Society (IRSS) Université catholique de Louvain; 2012.
26. Coumou D, Robinson A, Rahmstorf S: **Global increase in record-breaking monthly-mean temperatures.** *Clim Change* 2013, **118:**771–782.
27. Coumou D, Robinson A: **Historic and future increase in the global land area affected by monthly heat extremes.** *Environ Res Lett* 2013, **8:**034018.
28. Black H: **When to warn? comparing heat indices to evaluate public health risks.** *Environ Health Perspect* 2010, **118:**A35.
29. Anderson GB, Bell ML, Peng RD: **Methods to calculate the heat index as an exposure metric in environmental health research.** *Environ Health Perspect* 2013, **121:**1111–1119.
30. Morabito M, Crisci A, Messeri A, Capecchi V, Modesti PA, Gensini GF, Orlandini S: **Environmental temperature and thermal indices: what is the most effective predictor of heat-related mortality in different geographical contexts?** *Sci World J* 2014, **2014:**961750.
31. Handmer J, Honda Y, Kundzewicz ZW, Arnell N, Benito G, Hatfield J, Mohamed IF, Peduzzi P, Wu S, Sherstyukov B, Takahashi K, Yan Z: **Changes in impacts of climate extremes: human systems and ecosystems.** In *Manag Risks Extrem Events Disasters to Adv Clim Chang Adapt A Spec Rep Work Groups I II Intergov Panel Clim Chang (IPCC).* Edited by Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner

G-K, Allen SK, Tignor M, Midgley PM. Cambridge, New York: Cambridge University Press; 2012:231–290.
32. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA: **Impact of regional climate change on human health.** *Nature* 2005, **438:**310–317.
33. IPCC: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press; 2012:582.
34. Kalkstein A, Sheridan S: **The social impacts of the heat–health watch/warning system in Phoenix, Arizona: assessing the perceived risk and response of the public.** *Int J Biometeorol* 2007, **52:**43–55.
35. Abrahamson V, Wolf J, Lorenzoni I, Fenn B, Kovats S, Wilkinson P, Adger WN, Raine R: **Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK.** *J Public Health (Oxf)* 2009, **31:**119–126.
36. Gronlund CJ, Zanobetti A, Schwartz JD, Wellenius GA, O'Neill MS: **Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006.** *Env Heal Perspect* 2014. http://ehp.niehs.nih.gov/1206132/.
37. Schifano P, Cappai G, De SM, Bargagli AM, Michelozzi P: **Who should heat prevention plans target? A heat susceptibility indicator in the elderly developed based on administrative data from a cohort study.** *Heal Aging Res* 2013, **2:** http://dx.doi.org/10.12715/har.2013.2.2.
38. Sampson NR, Gronlund CJ, Buxton MA, Catalano L, White-Newsome JL, Conlon KC, O'Neill MS, McCormick S, Parker EA: **Staying cool in a changing climate: reaching vulnerable populations during heat events.** *Glob Environ Chang* 2013, **23:**475–484.
39. Bittner M-I, Matthies EF, Dalbokova D, Menne B: **Are European countries prepared for the next big heat-wave?** *Eur J Public Health* 2013, **24**(4):615–619.
40. Kovats RS, Kristie LE: **Heatwaves and public health in Europe.** *Eur J Public Health* 2006, **16:**592–599.
41. Ebi KL, Burton I: **Identifying practical adaptation options: an approach to address climate change-related health risks.** *Environ Sci Policy* 2008, **11:**359–369.
42. Lowe D, Ebi KL, Forsberg B: **Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves.** *Int J Environ Res Public Health* 2011, **8:**4623–4648.
43. Martinez GS, Imai C, Masumo K: **Local heat stroke prevention plans in Japan: characteristics and elements for public health adaptation to climate change.** *Int J Environ Res Public Heal* 2011, **8:**4563–4581.
44. Toloo G, Fitzgerald G, Aitken P, Verrall K, Tong S: **Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence.** *Int J Public Health* 2013, **58:**667–681.
45. **Critical appraisal skills programme: making sense of evidence.** http://www.casp-uk.net.
46. Katrak P, Bialocerkowski AE, Massy-Westropp N, Kumar S, Grimmer KA: **A systematic review of the content of critical appraisal tools.** *BMC Med Res Methodol* 2004, **4:**22.
47. Booth A, Papaioannou D, Sutton A: *Systematic Approaches to a Successful Literature Review.* Los Angeles [u.a.]: Sage; 2012.
48. Carroll C, Booth A, Lloyd-Jones M: **Should we exclude inadequately reported studies from qualitative systematic reviews? An evaluation of sensitivity analyses in two case study reviews.** *Qual Health Res* 2012, **22:**1425–1434.
49. Bargagli AM, Michelozzi P, Marino C, De Sario M, Schifano P, Cappai G, Perucci CA: **Heat health effect prevention: evaluation of the active surveillance program of high risk elderly in Rome, summer 2008.** *Epidemiology* 2009, **20:**S75–S75.
50. Bittner MI, Stößel U: **Perceptions of heatwave risks to health: results of an qualitative interview study with older people and their carers in Freiburg, Germany.** *Psychosoc Med* 2012, **9:**Doc05.
51. de'Donato FK, Michelozzi P, Bargagli A, Di Gennaro M, D'Ippoliti D, Leonardi MJ, Marino C, Schifimo P, Perucci C: **The Italian heat/health warning system for prevention of heat health effects; evaluation of summer 2008.** *Epidemiology* 2008, **19:**S287–S288.
52. Delaroziere JC, Sanmarco JL: **Excess mortality in people over 65 years old during summer heat waves in Marseille. comparison before and after a preventive campaign.** *Presse Med* 2004, **33:**13–16.
53. Fouillet A, Rey G, Wagner V, Laaidi K, Empereur-Bissonnet P, Le Tertre A, Frayssinet P, Bessemoulin P, Laurent F, De Crouy-Chanel P, Jougla E, Hémon D: **Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? a study of the 2006 heat wave.** *Int J Epidemiol* 2008, **37:**309–317.
54. Kishonti K, Paldy A, Bobvos J: **Evaluation of the communication of the heat-health-watch-warning system in Hungary.** *Epidemiology* 2006, **17:**S427–S428.
55. Kysely J, Kriz B: **Decreased impacts of the 2003 heat waves on mortality in the Czech Republic: an improved response?** *Int J Biometeorol* 2008, **52:**733–745.
56. Kyselý J, Plavcová E: **Declining impacts of hot spells on mortality in the Czech Republic, 1986–2009: adaptation to climate change?** *Clim Change* 2011, **113:**437–453.
57. Marinacci C, Marino M, Ferracin E, Fubini L, Gilardi L, Visentin P, Cadum E, Costa G: **Testing of interventions for prevention of heat wave related deaths: results among frail elderly and methodological problems.** *Epidemiol Prev* 2009, **33:**96–103.
58. Morabito M, Profili F, Crisci A, Francesconi P, Gensini GF, Orlandini S: **Heat-related mortality in the Florentine area (Italy) before and after the exceptional 2003 heat wave in Europe: an improved public health response?** *Int J Biometeorol* 2012, **56:**801–810.
59. Schifano P, Leone M, De Sario M, De'donato F, Bargagli AM, D'Ippoliti D, Marino C, Michelozzi P: **Changes in the effects of heat on mortality among the elderly from 1998–2010: results from a multicenter time series study in Italy.** *Environ Health* 2012, **11:**58.
60. Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM: **Changing heat-related mortality in the United States.** *Environ Health Perspect* 2003, **111:**1712–1718.
61. Ebi KL, Teisberg TJ, Kalkstein LS, Robinson L, Weiher RF: **Heat watch/warning systems save lives - estimated costs and benefits for Philadelphia 1995–98.** *Bull Am Meteorol Soc* 2004, **85:**1067–1073.
62. Mattern J, Garrigan S, Kennedy SB: **A community-based assessment of heat-related morbidity in North Philadelphia.** *Environ Res* 2000, **83:**338–342.
63. Ostro B, Rauch S, Green R, Malig B, Basu R: **The effects of temperature and use of air conditioning on hospitalizations.** *Am J Epidemiol* 2010, **172:**1053–1061.
64. Palecki MA, Changnon SA, Kunkel KE: **The nature and impacts of the July 1999 heat wave in the Midwestern United States: Learning from the lessons of 1995.** *Bull Am Meteorol Soc* 2001, **82:**1353–1367.
65. Rogot E, Sorlie PD, Backlund E: **Air-conditioning and mortality in hot weather.** *Am J Epidemiol* 1992, **136:**106–116.
66. Sheridan S: **A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness.** *Int J Biometeorol* 2007, **52:**3–15.
67. Smoyer KE: **A comparative analysis of heat waves and associated mortality in St. Louis, Missouri–1980 and 1995.** *Int J Biometeorol* 1998, **42:**44–50.
68. Weisskopf MG, Anderson HA, Foldy S, Hanrahan LP, Blair K, Torok TJ, Rumm PD: **Heat wave morbidity and mortality, Milwaukee, Wis, 1999 vs 1995: an improved response?** *Am J Public Health* 2002, **92:**830–833.
69. Chau P, Chan K, Woo J: **Hot weather warning might help to reduce elderly mortality in Hong Kong.** *Int J Biometeorol* 2009, **53:**461–468.
70. Tan J, Zheng Y, Song G, Kalkstein L, Kalkstein A, Tang X: **Heat wave impacts on mortality in Shanghai, 1998 and 2003.** *Int J Biometeorol* 2007, **51:**193–200.
71. Kosatsky T, Dufresne J, Richard L, Renouf A, Giannetti N, Bourbeau J, Julien M, Braidy J, Sauve C: **Heat awareness and response among Montreal residents with chronic cardiac and pulmonary disease.** *Can J Public Heal Can sante publique* 2009, **100:**237–240.
72. Oakman T, Byles-Drage H, Pope R, Pritchard J: **Beat the Heat: don't forget your drink - a brief public education program.** *Aust N Z J Public Health* 2010, **34:**346–350.
73. Bassil KL, Cole DC: **Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: a structured review.** *Int J Environ Res Public Health* 2010, **7:**991–1001.
74. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B: **Prognostic factors in heat wave related deaths: a meta-analysis.** *Arch Intern Med* 2007, **167:**2170–2176.
75. Gupta S, Carmichael C, Simpson C, Clarke MJ, Allen C, Gao Y, Chan EYY, Murray V: **Electric fans for reducing adverse health impacts in heatwaves.** *Cochrane Database Syst Rev* 2012, **7:**1–24.
76. Toloo GS, Fitzgerald G, Aitken P, Verrall K, Tong S: **Are heat warning systems effective?** *Environ Heal* 2013, **12:**27.

77. Andrieu D, Kaiser C, Ourednik A: **ScapeToad.** 2008.
78. Kyselý J, Plavcová E: **Declining impacts of hot spells on mortality in the Czech Republic, 1986–2009: adaptation to climate change?** *Clim Change* 2012, **113:**437–453.
79. Davis RE, Knappenberger PC, Novicoff WM, Michaels PJ: **Decadal changes in summer mortality in U.S. cities.** *Int J Biometeorol* 2003, **47:**166–175.
80. Frumkin H, Hess J, Luber G, Malilay J, McGeehin M: **Climate change: the public health response.** *Am J Public Health* 2008, **98:**435–445.
81. Ballester J, Robine J-M, Herrmann FR, Rodó X: **Long-term projections and acclimatization scenarios of temperature-related mortality in Europe.** *Nat Commun* 2011, **2:**358.
82. McMichael AJ, Woodruff RE, Hales S: **Climate change and human health: present and future risks.** *Lancet* 2006, **367:**859–869.
83. Adger WN, Agrawala S, Mirza MMQ, Conde C, O'Brien K, Pulhin J, Pulwarty R, Smit B, Takahashi K: **Assessment of adaptation practices, options, constraints and capacity.** In *Clim Chang 2007 Impacts, Adapt Vulnerability Contrib Work Gr II to Fourth Assess Rep Intergov Panel Clim Chang.* Edited by Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE. Cambridge: Cambridge University Press; 2007:717–743.
84. McMichael AJ: **Globalization, climate change, and human health.** *N Engl J Med* 2013, **368:**1335–1343.
85. Programme of Research on Climate Change Vulnerability Impacts and Adaptation (PROVIA): *Research Priorities on Vulnerability, Impacts and Adaptation: Responding to the Climate Change Challenge.* Nairobi: PROVIA; 2013.
86. Cheng JJ, Berry P: **Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature.** *Int J Public Health* 2013, **58:**305–311.
87. Hallegatte, S: **Strategies to adapt to an uncertain climate change.** *Glob Environ Chang* 2009, **19**(2):240–247.
88. Hall JW, Brown S, Nicholls RJ, Pidgeon NF, Watson RT: **Proportionate adaptation.** *Nat Clim Chang* 2012, **2:**833–834.
89. Füssel H-M: **Adaptation planning for climate change: concepts, assessment approaches, and key lessons.** *Sustain Sci* 2007, **2:**265–275.
90. Wilby RL, Dessai S: **Robust adaptation to climate change.** *Weather* 2010, **65:**180–185.
91. Wilby RL, Vaughan K: **Hallmarks of organisations that are adapting to climate change.** *Water Environ J* 2011, **25:**271–281.
92. McMichael AJ: **Impediments to comprehensive research on climate change and health.** *Int J Environ Res Public Health* 2013, **10:**6096–6105.
93. Bassil KL, Cole DC, Smoyer-Tomic K, Callaghan M, Team HEPHIR: *What Is the Evidence on Applicability and Effectiveness of Public Health Interventions in Reducing Morbidity and Mortality during Heat Episodes?.* Toronto: National Collaborating Centre for Environmental Health; 2007.
94. Biesbroek GR, Swart RJ, Carter TR, Cowan C, Henrichs T, Mela H, Morecroft MD, Rey D: **Europe adapts to climate change: comparing national adaptation strategies.** *Glob Environ Chang* 2010, **20:**440–450.
95. Berrang-Ford L, Ford JD, Paterson J: **Are we adapting to climate change?** *Glob Environ Chang* 2011, **21:**25–33.
96. Bobb JF, Peng RD, Bell ML, Dominici F: **Heat-related mortality and adaptation to heat in the United States.** *Env Heal Perspect* 2014, **122:**811–816.
97. Coates L, Haynes K, O'Brien J, McAneney J, de Oliveira FD: **Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010.** *Environ Sci Policy* 2014, **42:**33–44.
98. Petkova EP, Gasparrini A, Kinney PL: **Heat and mortality in New York City since the beginning of the 20th century.** *Epidemiology* 2014, **25:**554–560.
99. Smith KR, Woodward A, Campbell-Lendrum D, Chadee D, Honda Y, Liu Q, Olwoch J, Revich B, Sauerborn R, Aranda C, Berry H, Butler C, Chafe Z, Cushing L, Ebi K, Kjellstrom T, Kovats S, Lindsay G, Lipp E, McMichael T, Murray V, Sankoh O, O'Neill M, Shonkoff SB, Sutherland J, Yamamoto S: **Human health: impacts, adaptation and co-benefits.** In *Intergov Panel Clim Chang 5th Assess Rep.* Stanford: IPCC; 2014.

doi:10.1186/1471-2458-14-1112
Cite this article as: Boeckmann and Rohn: Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC Public Health* 2014 **14**:1112.

Article II

Boeckmann, M., & Joyner, T. A. (2014). **Old health risks in new places? An ecological niche model for I. ricinus tick distribution in Europe under a changing climat**e. *Health & Place*, *30C*, 70–77. doi:10.1016/j.healthplace.2014.08.004

Health & Place 30 (2014) 70–77

Contents lists available at ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

Old health risks in new places? An ecological niche model for *I. ricinus* tick distribution in Europe under a changing climate

Melanie Boeckmann [a,b,*], T. Andrew Joyner [c]

[a] Leibniz Institute for Prevention Research and Epidemiology – BIPS, Department Prevention and Evaluation, Bremen, Germany
[b] Center for Social Policy Research, University of Bremen, Germany
[c] 308 Ross Hall, East Tennessee State University, Department of Geosciences, Johnson City, TN 37614, USA

ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form
30 June 2014
Accepted 16 August 2014

Keywords:
Tick-borne diseases
Climate change
Ecological niche model
Vector-borne diseases
Climate change adaptation

ABSTRACT

Climate change will likely have impacts on disease vector distribution. Posing a significant health threat in the 21st century, risk of tick-borne diseases may increase with higher annual mean temperatures and changes in precipitation. We modeled the current and future potential distribution of the *Ixodes ricinus* tick species in Europe. The Genetic Algorithm for Rule-set Prediction (GARP) was utilized to predict potential distributions of *I. ricinus* based on current (1990–2010 averages) and future (2040–2060 averages) environmental variables. A ten model best subset was created out of a possible 200 models based on omission and commission criteria. Our results show that under the A2 climate change scenario the potential habitat range for the *I. ricinus* tick in Europe will expand into higher elevations and latitudes (e.g., Scandinavia, the Baltics, and Belarus), while contracting in other areas (e.g., Alps, Pyrenees, interior Italy, and northwestern Poland). Overall, a potential habitat expansion of 3.8% in all of Europe is possible. Our results may be used to inform climate change adaptation efforts in Europe.

1. Introduction

Climate change has substantial impacts on human health (Costello et al., 2011; Frumkin et al., 2008; Haines et al., 2006; McMichael and Lindgren, 2011; Patz et al., 2005). Impacts on the European continent will likely include a higher frequency of extreme weather events, prolonged heat waves, changes in precipitation, reduction in biodiversity, and changes in the spatial distribution of various infectious diseases (Bittner et al., 2014; Confalonieri et al., 2007; Fischer and Schär, 2010; Nikulin et al., 2011; Parks et al., 2010; Semenza et al., 2012; Thuiller et al., 2005). In addition to a potential increase in food-borne infections with warmer mean temperatures (Thomas et al., 2012), the distribution and life cycle changes of rodents, arthropods, and other disease vectors present a major public health risk to Europe (Ciscar et al., 2011; Semenza and Menne, 2009; Semenza et al., 2012). Vector-borne diseases are transmitted by ticks (e.g., tick-borne encephalitis (TBE), Lyme borreliosis), mosquitoes (e.g., West Nile Virus, malaria, dengue), sandflies (e.g., leishmaniasis), rodents (e.g., plague, hantavirus), and other arthropods. While risks to Europe from emerging tropical diseases under a changing climate should not be dismissed, morbidity from tick-borne diseases is already a public health issue in Europe that may be exacerbated by climatic change (Jaenson and Lindgren, 2011; Massad et al., 2011; Semenza et al., 2012). In Europe's temperate climate, ticks are the primary disease vector (Capelli et al., 2012a), and assessing future perturbations in tick distribution under a changing climate is an imperative component of climate change adaptation and public health preparedness (Semenza et al., 2012).

1.1. Climate change effects on tick-borne diseases

Already endemic in northern and central Europe, ticks of the *Ixodes ricinus* (subsequently called *I. ricinus*) family act as both a reservoir and vector for lyme borreliosis and TBE pathogens (Jaenson and Lindgren, 2011; Jaenson et al., 2012; Lindquist and Vapalahti, 2008; Süss, 2011). Climate change affects vector-borne disease distribution and incidence through various paths (Gage et al., 2008; Kovats et al., 2001; Mills et al., 2010; Semenza et al., 2012). First, arthropod vectors such as ticks are ectothermic (cold-blooded) and therefore sensitive to changes in temperature (European Center for Disease Prevention and Control, 2012). Secondly, precipitation and humidity additionally affect reproduction and egg development, vector development, population density as well as biting activity (Gage et al., 2008; Harrus and Baneth, 2005; Knap et al., 2009). Pathogen load, pathogen development, abundance of host species and human behavior are also affected by climate factors (Kovats et al., 2001; Massad et al., 2011; Semenza

* Correspondence to: Leibniz Institute for Prevention Research and Epidemiology – BIPS, Department Prevention and Evaluation, Achterstr. 30, 28359 Bremen, Germany. Tel.: +49 421 218 58545.
E-mail addresses: melanie.boeckmann@bips.uni-bremen.de (M. Boeckmann), joynert@mail.etsu.edu (T.A. Joyner).

http://dx.doi.org/10.1016/j.healthplace.2014.08.004
1353-8292/

and Menne, 2009; Zhang et al., 2008). *I. ricinus* spends all of its life stages outside and thus depends on a suitable combination of climate variables making them particularly vulnerable to changes in climate (Estrada-Peña, 2008; Gage et al., 2008). Milder winters and longer growing seasons could expand climate-sensitive vector ranges to higher altitudes and latitudes (Süss, 2011), while a hotter and drier climate in southern European countries might lead to a decrease in tick abundance in these regions (Semenza and Menne, 2009). Temperate environments have also been described as particularly at risk from global warming as low temperatures usually limit vector survival (Sutherst, 2004). European countries with lower mean temperatures are expected to experience an increase in climate-sensitive disease vectors in the near future (Semenza et al., 2012).

In recent years, the public health research community has become increasingly interested in future impacts of climate change on human health as shown by a larger output of research articles (Hosking and Campbell-Lendrum, 2012). Whereas future distribution of ticks in individual European countries has been modeled (Gray et al., 2009), transfer of these results of spatial epidemiological modeling into national adaptation policy has been slow. Limited information exists on changes in tick niche distribution on the European continent overall, a gap which this study attempts to fill. Based on our results of modeling current and prospective *I. ricinus* tick distribution in Europe, we discuss the potential implementation of our methods into European climate change adaptation strategies.

2. Materials and methods

2.1. Data sources

A total of 2097 georeferenced localities (presence-only) for *I. ricinus* were obtained from the Global Biodiversity Information Facility (2013). Most tick localities were recorded using handheld GPS, while coordinates for older records were documented using local maps and distance and azimuth (direction) from the nearest town. The majority of ticks (~97%) were collected from their observed presence on a host (e.g., human, dog), then mailed to a public health station or museum. The remaining ticks were observed and not collected. Absence data were not needed for the chosen method of modeling. More than one species was recorded at multiple locations, providing a rudimentary level of abundance. However, abundance was also not necessary for modeling and only one *I. ricinus* tick was needed per geographically unique location. GBIF is a global inventory of freely available species locality data that combines multiple datasets into one. Only data from European countries were used in this study and the original data sources include the Ohio State University Acarology Collection, Berlin Museum of Natural History, Illinois Natural History Survey, National Natural History Museum of Luxembourg, United Kingdom National Biodiversity Network, Danish Biodiversity Information Facility, Swedish Species Data Bank, Natural History Museum – University of Oslo, and Norwegian Species Data Bank.

The current distribution model utilized baseline climate data constructed of averages over the time period 1990–2010 and the future distribution model utilized the CSIRO SRES A2 emissions scenario for the time period 2040–2060. The A2 scenario was originally created by the CSIRO Marine and Atmospheric Research Laboratories Information Network in Australia (Collier et al., 2007; Gordon et al., 2002). Data were obtained from the Consultative Group on International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CCAFS) global circulation model (GCM) data portal (Consultative Group on International Agricultural Research (CGIAR), 2013). The A2 emissions scenario uses global economic and industrial trend predictions to conceptualize a future climate influenced by a heterogeneous world where fertility patterns converge slowly across regions resulting in increasing population, while economic growth and technological change are regionally fragmented. Because the impact of these trends is expected to exacerbate current climate change tendencies, the A2 scenario is considered a "high" emissions scenario. Both the baseline climate data and A2 scenario climate data were processed and downscaled through the MarkSim pattern scaling technique, which groups over 9200 global weather stations into climate clusters based on monthly average rainfall and temperature figures from each station (Jones and Thornton, 2013).

Bioclimatic grids were created through the manipulation of monthly measures of solar radiation, precipitation, and temperature and included annual mean solar radiation, iso-thermality, annual total precipitation, precipitation of wettest quarter, and precipitation of driest quarter at a resolution of 5′ (~8 km) (Hijmans et al., 2005). Soil type was also used as a variable for modeling because of its importance in tick habitat suitability (Guerra et al., 2002). Soil data were obtained from the Harmonized World Soil Database (HWSD), which utilized the Soil and Terrain Database (SOTER) for Europe. Soil data were available at a resolution of 30″ (~1 km). All variables were resampled to a resolution of 8 km^2 (or 0.01°), and clipped to the boundary of Europe (excluding western Russia).

2.2. The GARP modeling approach

The Genetic Algorithm for Rule-set Prediction (GARP) was selected to create an ecological niche model (ENM) for *I. ricinus*. The GARP model was developed using the Desktop GARP version 1.1.3 open source software application (Scachetti-Pereira and Stockwell, 2002). GARP is a presence-only modeling tool that analyzes the relationship between locality data and the parameters of environmental variables in the same location through an iterative process of training and testing (Stockwell and Peters, 1999). A total of 50 rules are created from four main rule types (atomic, range, negated range, and logit rules) for each model run in a pattern matching process that finds non-random relationships between locality data and environmental parameters. Once a rule-set (i.e., the combination of all 50 rules in each model run) is created, then the relationship is applied to other areas of the landscape that have similar environmental parameters describing either presence or absence of the species. Validation occurs both internally and externally through a process of data splitting that is user-defined.

The GARP modeling approach is stochastic, or random, and consequently produces different outputs with each model run. Because of the variance between each model run output, it is important to produce multiple runs and utilize the best-subset technique of selecting the 10 best models that meet certain optimization parameters. Omission and commission thresholds are defined by the user to obtain a set of models that find a balance between sensitivity (absence of omission error) and specificity (absence of commission error) (Anderson et al., 2003). The resulting GARP output is a collection of grids that describe presence and absence of the species across the study area. These grids can be input in a Geographic Information System (GIS) and summated to find areas where higher and lower model agreement occurs. Presence or absence classification is more certain with increasing model agreement (Ron, 2005).

2.3. Application of GARP in this study

For this study, a total of 904 *I. ricinus* locations were found to be spatially unique and thus available for evaluation. Locations were spatially unique when they were not found in the same eight

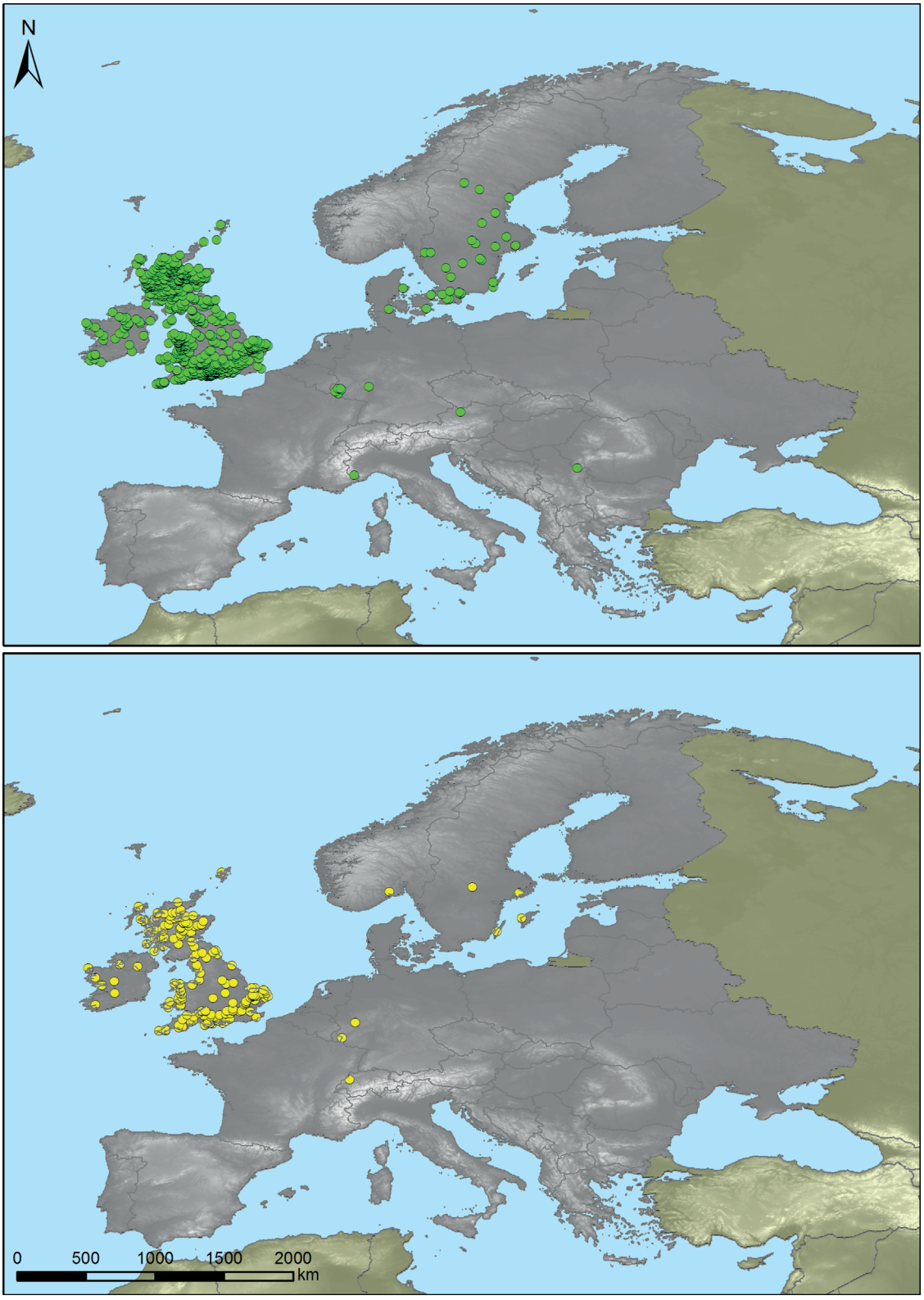


Fig. 1. Training (green) species locality data were used for model building, and testing (yellow) species locality data were used to test model accuracy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

square kilometers (the resolution used in this study) as another location. GARP does not weight grid cells based on quantity and it is therefore unnecessary to have more than one occurrence per grid cell. Subsets of training and independent data were created by randomly splitting each dataset. For each species, a subset of ~20% was withheld from the model-building process for post-hoc model evaluation (independent data). The remaining ~80% was used for model-building (training data). Each model run used a 50/50 internal training/testing split with a maximum of 200 runs and a convergence limit of 0.01. The convergence limit is a measure of change between rule-sets from one model to the next and values closer to 0 infer increasing iterative model stability.

A convergence limit of 0.01 assumes a high level of inter-model stability between subsets when GARP is complete. The "max iterations" was set to 1000 and all rule types were applied. A best subset was selected with an extrinsic omission measure (i.e., the percentage of test points omitted from the prediction within the model) and a hard omission threshold (i.e., the percentage of total points allowed to be omitted from a final rule-set) of 10%. The total "models under the hard omission threshold" was set to 20 and the commission threshold was set to 50% of the distribution.

Accuracy metrics utilized the ~20% independent data that were withheld from the model-building experiments for each species to test the model outputs. Areas under the curve (AUC) scores were produced using a receiver operating characteristic (ROC). Two measures of omission (total and average) and two measures of commission (total and average) were also calculated for each model output. Omission describes the percentage of occurrence data excluded from the areas predicted to be present for the species, while commission describes the percentage of the study area predicted to be present for the species. Commission only describes the area predicted to be present and does not infer a correctly predicted area, but is instead used as a counterweight to omission. The AUC measures specificity (commission) vs. sensitivity (omission) in an effort to balance the two metrics. An AUC score ranges from 0.5 (lowest predictive accuracy – completely random) to 1.0 (perfect score – points were predicted 100% of the time).

Agreement between the current and future projections of potential *I. ricinus* distributions was examined to determine areas of expansion and contraction. The best subset output of ten models was divided in half to represent presence or absence (presence predicted in 0–5 models=classified as absent; presence predicted in 6+ models=classified as present). The resulting presence/absence grids were combined to highlight areas where no models, one model, or both models predicted presence or absence on the landscape.

3. Results

Most original tick locality data were found in the United Kingdom with additional occurrences located in Sweden, Denmark, Luxembourg, Germany, Switzerland, Italy, Austria, and Serbia (Fig. 1). The random subset training and testing datasets represented examples for modeling and testing in most locations thus providing robust model building and validation. A "good fit" for the current potential distribution increases our level of confidence in the future potential distribution of *I. ricinus* since the future model is dependent on the current model. Accuracy metrics revealed a very low total omission of 2.0 meaning that only 2% of all testing occurrence locations were excluded from the final 10-model best subset (Table 1). The average omission of 2.7 indicated that 97.3% of all validation data were predicted correctly on average by all models in the best subset. Approximately 15.4% of the modeled landscape was predicted by all 10 of the best models to be part of the ecological niche for *I. ricinus* based on the total commission score of 15.4. An AUC score of 0.91 ($p < 0.01$) indicated very high model accuracy. Additionally, based on the internal accuracy metrics set within the GARP model (i.e., omission/commission thresholds and the convergence limit), the convergence of accuracy was achieved prior to reaching 1000 model iterations.

The results of the current and future potential distribution GARP models illustrate that the northern areas of Europe provide suitable niche spaces for the *I. ricinus* ticks (Fig. 2). The predicted current distribution, our baseline, covers most of the United Kingdom, Ireland, The Netherlands, Belgium, and Denmark, while large areas of Sweden, Norway, Germany, France, and Sweden are also part of the current *I. ricinus* potential distribution. Parts of Spain, Italy, Austria, Croatia, the Czech Republic, Baltics, and Finland also provide smaller areas of habitat suitability. Areas of high model agreement (or high habitat suitability) in southern Europe are concentrated in mountainous regions such as the Alps of Switzerland, Austria, and northern Italy as well as the Pyrenees of northern Spain and southern France. Three or fewer models predicted presence of *I. ricinus* in central France and Germany as well as many smaller areas in multiple countries across Europe. This low level of model agreement indicates a lower likelihood of suitable habitat for *I. ricinus*.

Table 1
Accuracy metrics for the current distribution model of *I. ricinus*.

Metric	Values
n to build models	723[†]
n to test models	181
Total omission	2.0
Average omission	2.7
Total commission	15.4
Average commission	29.0
AUC[*]	0.91 ($z=22.11$;[‡], SE=0.02)

[†] *n* was divided into 50% training/50% testing at each model iteration.
[*] AUC=area under curve.
[‡] $p < 0.001$.

Based on current and future potential distribution models, our results show that under climate change scenario A2 the potential habitat range for *I. ricinus* ticks in Europe will expand at higher elevations and latitudes (e.g., Scandinavia, the Baltics, and Belarus), while contracting in other areas (e.g., Alps, Pyrenees, interior Italy, and northwestern Poland) (Fig. 3). Most contraction occurs on the lower latitude and lower elevation fringes of the current potential distribution. The largest area of contraction occurs in western Poland in an area of lower elevation. Scattered areas of contraction also occur at the lower elevations of the Pyrenees and Alps as well as lower elevations in central and southern Italy.

Overall potential habitat area will expand from 24.2% of the modeled area (i.e., areas with 6+ model agreement) to 28.0% – a net habitat expansion of 3.8% when examining all of Europe (Table 2). The table accurately quantifies changes in absence and presence areas for *I. ricinus*, but masks the spatial heterogeneity of habitat change since areas of expansion and contraction cancel each other out, resulting in a seemingly small amount of habitat expansion. Expansion in some countries (e.g., Belarus, Sweden, Finland, and the Baltics) approaches 15%, while contraction is relatively high in other countries, most notably Poland and Italy.

4. Discussion

Our results show a likely expansion of up to 3.8% suitable habitats for *I. ricinus* ticks in Europe under the A2 climate change scenario, despite a projected ecological niche contraction in the Alps, the Pyrenees, inland Italy and large parts of Poland. Specifically, the countries of Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Belarus, and Denmark are expected to experience areas of expansion, while Croatia, Italy, France, Spain, and Germany are expected to experience areas of contraction. Poland will actually have large sections of both expansion and contraction with areas of contraction occurring near its western border with Germany and areas of expansion occurring along its northern central coast. Results allude to the spatial heterogeneity of expansion and contraction with larger areas of expansion occurring in northern countries/regions, whereas

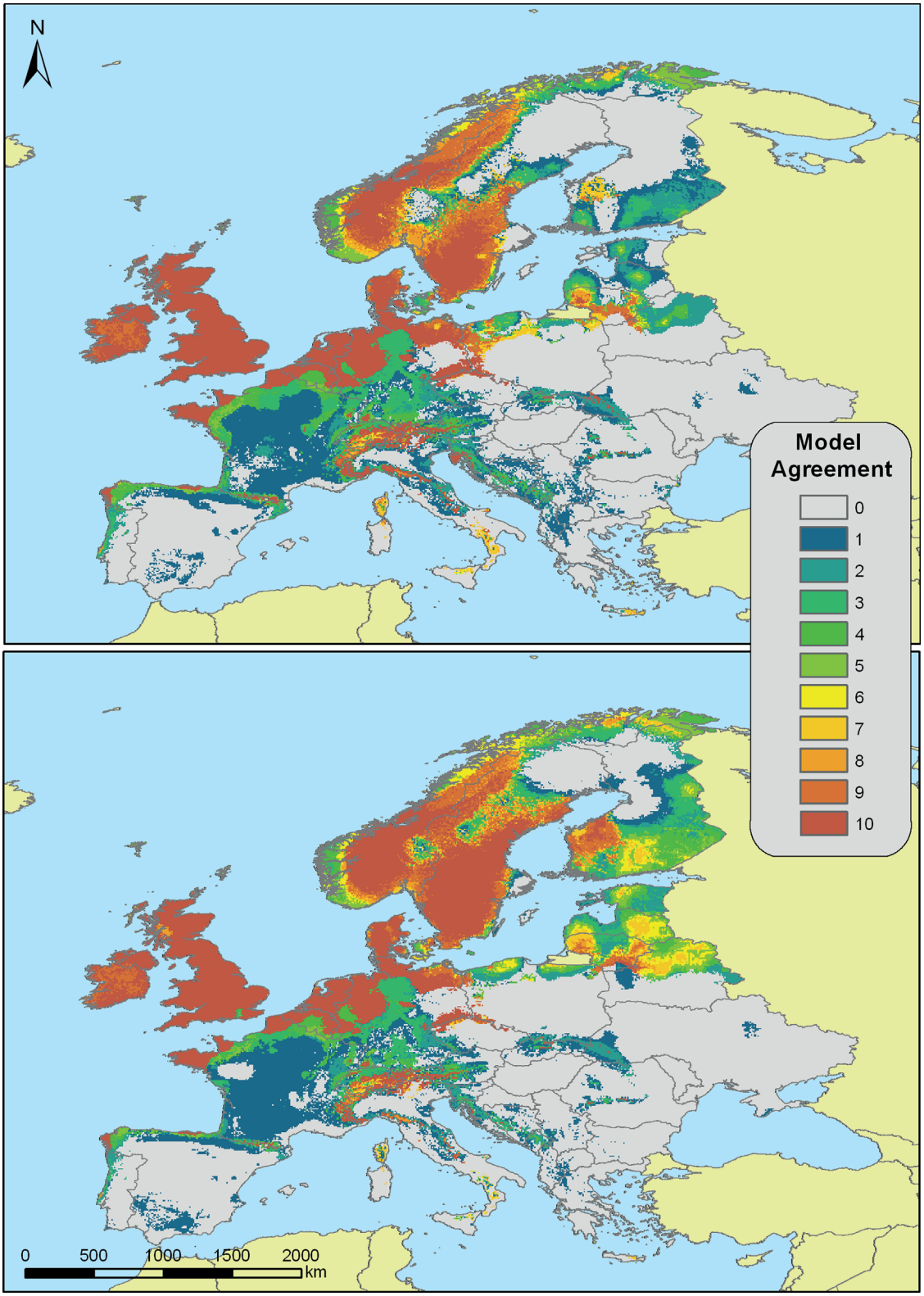


Fig. 2. Current potential distribution (top) and future potential distribution (bottom) of *I. ricinus* under a changing climate.

larger areas of contraction are expected in southern countries/regions. Small areas of expansion/contraction in mountainous regions reveal an upslope movement in *I. ricinus* potential habitat.

Consequently, the health risks associated with tick-borne diseases may increase in the areas of expanded *I. ricinus* habitat. As most current *I. ricinus* habitats will remain suitable for the vector in our scenario, the existing burden of tick-borne diseases in Europe should not be neglected. It might be useful to increase efforts to reduce the current health risks from ticks in Europe as part of climate change adaptation strategies, while at the same time preparing regions with a potential future suitable tick habitat for a possible increase in disease burden.

Our results confirm other recent vector niche modeling studies (Carbajo et al., 2012; Jaenson and Lindgren, 2011; Roiz et al., 2011).

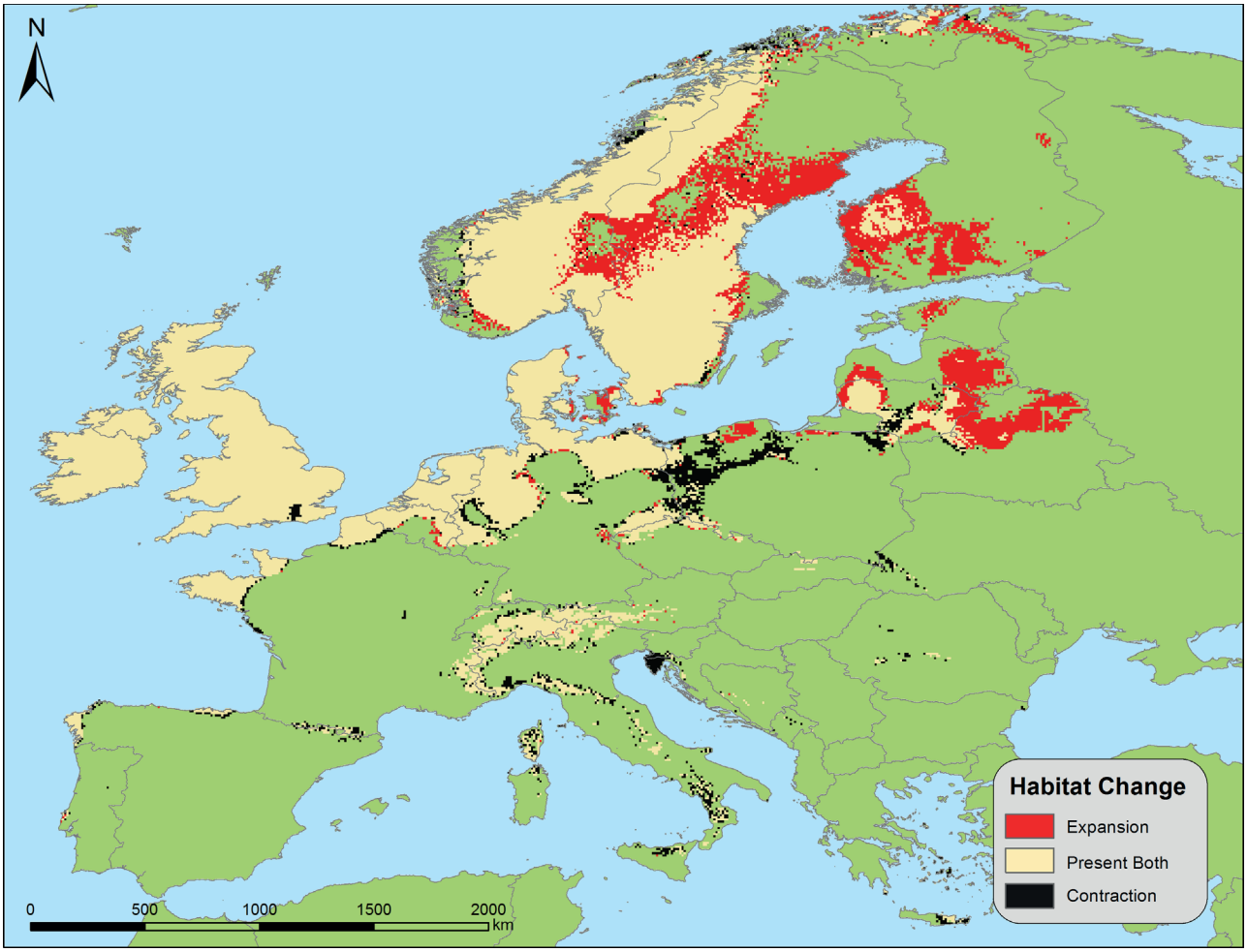


Fig. 3. Predicted changes in potential habitat for *I. ricinus*.

Table 2
Absence and presence of *I. ricinus* in current and future potential distribution models. The future distribution is expected to expand by ~4%.

Model		Absence		Presence	
Current	Percent		76%		24%
	Square km	4,384,503.71		1,402,051.34	
Future	Percent		72%		28%
	Square km	4,165,817.39		1,620,737.66	

Climate change will likely influence the environmental variables determining tick distribution. This study utilized soil type as a variable within the GARP model and this variable will not change at the same rate as purely climatic variables. Soil, therefore, serves to temper the potential shift in habitat suitability for *I. ricinus*. Additionally, this study was one of the first to use the MarkSim pattern-scaling climate simulation model method for an ENM. MarkSim is often better at simulating and predicting climate variances in temperate climates than other climate modeling methods since it examines each unique location in an area and employs stochastic downscaling and weather typing to closely model actual climatic variance within specific climate clusters.

Through the use of both dynamic (climatic) and relatively static (soil type) variables, valuable current and future tick distribution information can be collected from the GARP model. The broader question is whether these data can be applied to climate change adaptation planning to reduce the future burden of disease?

4.1. Application of spatial epidemiological modeling to adaptation practice in Europe

Evidence for effective vector-borne disease adaptation is sparse (Semenza et al., 2012). Various approaches have been suggested, for instance, strengthening public health infrastructure, disease surveillance and monitoring; information and education campaigns, awareness raising among stakeholders, access to healthcare, vector control, vaccine development and further research (Gage et al., 2008; Lindquist and Vapalahti, 2008; Semenza and Menne, 2009; Sutherst, 2004). Disease surveillance and monitoring are the main efforts currently outlined in the European climate change adaptation strategy (European Commission, 2013). Whereas impact assessments are necessary to quantify future risks and are standardly requested in current climate change strategies in Europe (European Commission, 2013), information on current and future distribution of ticks is needed. Low model agreement in much of France, Germany, Finland, and other countries signifies that the *I. ricinus* tick may not find a suitable habitat in these locations, but it is still possible for *I. ricinus* to survive and thrive in these areas. Disease monitoring should not cease in these areas, but with limited resources surveillance should concentrate on the areas with the highest levels of model agreement (Fig. 2).

The European Centers for Disease Control encourage integrated approaches to disease surveillance (Braks et al., 2011). Such integrated approaches may combine clinical data and vector presence/absence data and include both disease and vector monitoring (Braks

et al., 2011). We suggest that our model can support this endeavor by providing a good estimate of presence and abundance localities that might be complemented with clinical or syndromic data collection. Kalluri et al. (2007) suggested using remote sensing of vegetation indices as proxies for meteorological variables in vector surveillance. Applying remote sensing techniques could be a second step after identifying areas likely to be at risk through our projections. Validating the model results through tick presence monitoring is advisable, yet poses its own challenges as it is both time – and resource – consumptive. Expenses might be reduced through choosing cost-effective sampling strategies as demonstrated in a previous study (Capelli et al., 2012b). Our approach can support such a strategy by directing tick monitoring to the areas of potential current and future habitats. As our methods are based on open-source software and freely available data, these methods might make surveillance feasible for local municipalities with limited resources.

Additionally, when considering future potential distributions based on predicted changes in climate, increased and improved surveillance efforts should be targeted in areas of predicted habitat expansion. Some parts of the Baltics and Finland were not identified as areas of potential habitat expansion in Fig. 3 when only examining areas with high (6+) model agreement, but an examination of the future potential distribution of *I. ricinus* in Fig. 2 reveals large areas that were not predicted to have a suitable environment by any models in the current GARP model and now have up to 5 models predicting potential habitat suitability. These areas should be monitored closely for rapid habitat expansion depending on how climate change is manifested in the region and how the tick is able to adapt to a changing environment. Our results show that information for improved monitoring and surveillance can be provided at both the national and international level with GARP. In addition, using open source software aids in more informed decision-making at reasonable costs. As tick-borne diseases are already a public health issue in Europe, less resource-intensive methods may contribute to a quicker uptake of public health prevention measures in areas at risk, both now and in the future.

4.2. Limitations of our approach

To estimate vector distribution now and in the future, ideally vectors would be trapped, collected, counted and their pathogen load analyzed (Guerra et al., 2002). However, this long-term, data intensive study type requires a substantial amount of time and resources, both of which are often in short supply for policy-makers. While other intensive collection techniques (e.g., flagging, walking, trapping, raking, sweeping) may provide better coverage in some areas of Europe where data were sparse, the location of available data from GBIF was representative of their endemic environment and the identification of the signature of each environment is the most important component for niche modeling where an environmental pattern is matched to species locality. The matching environment is then predicted geographically in areas of sparse or no data collection, thus providing an accurate prediction of the species' potential habitat and an added benefit of identifying locations where more sampling and surveillance should occur.

GARP utilizes actual species locality data, soil data, and climate variable data, therefore only partially relying on climate data. Nonetheless, at the continental level, climate and environmental variables have been described as good predictors of future vector-borne disease distribution (Kovats et al., 2001; Morin et al., 2013; Yamana and Eltahir, 2013). We chose the SRES A2 model as our climate model, but any scenario has inherent uncertainties. Subsequent studies will model the potential distribution of *I. ricinus* under multiple scenarios to identify a range of areas at risk and to provide a more expansive roadmap to follow when considering adaptation strategies.

In addition to a comparison of climate change scenarios, individual rule-sets within GARP should be examined. The GARP model in this study revealed an increasingly fragmented distribution in southern Europe potentially resulting in smaller and more isolated *I. ricinus* populations that may evolve into genetically unique subspecies or clades (Estrada-Peña, 2008). Future research may focus on mapping specific dominant rules on the landscape to see if there are certain rules that apply at different latitudes – this could indicate that *I. ricinus* already exhibits some signs of sub-speciation.

Uncertainties about the quantitative relationship between climatic variables and the transmission of vector-borne diseases remain an issue. While climate change alone is unlikely to explain recent shifts in the geographical distribution of vectors (Randolph, 2013), emerging evidence for a large role of climate in these shifts exists (Confalonieri et al., 2007; Süss, 2011). For the *I. ricinus* tick, altitudinal and latitudinal range shifts in Europe have been observed in conjunction with an increased incidence of TBE (Gage et al., 2008; Mills et al., 2010). Thus, our modeling results corroborate recent observed distribution changes.

5. Conclusion

Careful examination of all possible reasons for these observed shifts is necessary, as lack of data on the baseline distribution of vectors, detection bias, and anthropogenic factors such as land use changes may affect correlations. The evidence available nonetheless shows an increased risk of vector-borne diseases in Europe over the past decades. This risk might be exacerbated by future climatic changes.

Despite the limitations inherent to modeling future conditions, our study results suggest that modeling the ecological niche with GARP is a useful approach to identify regions where climate change adaptation strategies for tick-borne diseases should target and address the current gap between models and strategies.

Authors' contributions

MB and TAJ both conceived of and designed the study. MB conducted the literature review. TAJ designed the model, and collected and analyzed the data. MB and TAJ developed the manuscript together. All authors approved the final manuscript.

Acknowledgments

MB was supported by a University of Bremen and Leibniz Institute for Prevention Research and Epidemiology – BIPS joint PhD scholarship. This collaboration was initially facilitated by the National Science Foundation (NSF) and the German Research Foundation (DFG). Preliminary results of this research were presented as a poster at the 2013 Annual Conference of the German Epidemiological Society. We thank Prof. Hajo Zeeb and Prof. Robert V. Rohli for helpful comments and critical revision of the manuscript. The anonymous reviewers have given useful suggestions; we would like to thank them for their thoughtful comments.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.healthplace.2014.08.004.

These data include Google maps of the most important areas described in this article.

References

Anderson, R.P., Lew, D., Peterson, A.T., 2003. Evaluating predictive models of species' distributions: criteria for selecting optimal models. Ecol. Modell. 162, 211–232.

Bittner, M.-I., Matthies, E.F., Dalbokova, D., Menne, B., 2014. 2014. Are European countries prepared for the next big heat-wave? Eur. J. Public Health 24, 615–619. http://dx.doi.org/10.1093/eurpub/ckt121.

Braks, M., van der Giessen, J., Kretzschmar, M., van Pelt, W., Scholte, E.J., Reusken, C., Zeller, H., van Bortel, W., Sprong, H., 2011. Towards an integrated approach in surveillance of vector-borne diseases in Europe. Parasites Vectors 4, 192. http://dx.doi.org/10.1186/1756-3305-4-192.

Capelli, G., Ravagnan, S., Montarsi, F., Ciocchetta, S., Cazzin, S., Porcellato, E., Babiker, A.M., Cassini, R., Salviato, A., Cattoli, G., Otranto, D., 2012a. Occurrence and identification of risk areas of Ixodes ricinus-borne pathogens: a cost-effectiveness analysis in north-eastern Italy. Parasites Vectors 5, 61.

Capelli, G., Ravagnan, S., Montarsi, F., Ciocchetta, S., Cazzin, S., Porcellato, E., Babiker, A.M., Cassini, R., Salviato, A., Cattoli, G., Otranto, D., 2012b. Occurrence and identification of risk areas of Ixodes ricinus-borne pathogens: a cost-effectiveness analysis in north-eastern Italy. Parasites Vectors 5, 61. http://dx.doi.org/10.1186/1756-3305-5-61.

Carbajo, A.E., Cardo, M.V., Vezzani, D., 2012. Is temperature the main cause of dengue rise in non-endemic countries? The case of Argentina. Int. J. Health Geogr. 11, 26.

Ciscar, J.-C., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O.B., Dankers, R., Garrote, L., Goodess, C.M., Hunt, A., Moreno, A., Richards, J., Soria, A., 2011. Physical and economic consequences of climate change in Europe. Proc. Natl. Acad. Sci. U. S. A. 108, 2678–2683. http://dx.doi.org/10.1073/pnas.1011612108.

Collier, M.A., Dix, M.R., Hirst, A.C., 2007. CSIRO Mk3 Climate System Model and Meeting the Strict IPCC AR4 Data Requirements. In: Oxley, L., Kulasiri, D. (Eds.), MODSIM07 International Congress on Modelling and Simulation. Land, Water & Environmental Management: Integrated Systems for Sustainability. Christchurch: Modelling and Simulation Society of Australia and New Zealand, Christchurch, pp. 582–588.

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B., Woodward, A., 2007. Human health. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 391–431.

Consultative Group on International Agricultural Research (CGIAR), 2013. Research Program on Climate Change, Agriculture and Food Security (CCAFS) [WWW Document]. URL ⟨http://www.ccafs-climate.org/⟩ (accessed 10.18.13.).

Costello, A., Maslin, M., Montgomery, H., Johnson, A.M., Ekins, P., 2011. Global health and climate change: moving from denial and catastrophic fatalism to positive action. Philos. Trans. A Math. Phys. Eng. Sci. 369, 1866–1882.

Estrada-Peña, A., 2008. Climate, niche, ticks, and models: what they are and how we should interpret them. Parasitol. Res. 103 (Suppl), S87–S95. http://dx.doi.org/10.1007/s00436-008-1056-7.

European Center for Disease Prevention and Control, 2012. Ticks can carry disease [WWW Document]. URL ⟨http://www.ecdc.europa.eu/en/healthtopics/emerging_and_vector-borne_diseases/tick_borne_diseases/tick_borne_encephalitis/key-messages/Pages/Ticks-carry-disease.aspx⟩ (accessed 12.12.13.).

European Commission, 2013. An EU Strategy on adaptation climate change: adaptation to climate change impacts on human, animal and plant health.

Fischer, E.M., Schär, C., 2010. Consistent geographical patterns of changes in high-impact European heatwaves. Nat. Geosci. 3, 398–403. http://dx.doi.org/10.1038/ngeo866.

Frumkin, H., Hess, J., Luber, G., Malilay, J., McGeehin, M., 2008. Climate change: the public health response. Am. J. Public Health 98, 435–445.

Gage, K.L., Burkot, T.R., Eisen, R.J., Hayes, E.B., 2008. Climate and vectorborne diseases. Am. J. Prev. Med. 35, 436–450.

Global Biodiversity Information Facility [WWW Document], 2013. URL ⟨http://www.gbif.org⟩ (accessed 10.18.13).

Gordon, H.B., Rotstayn, L.D., McGregor, J.L., Dix, M.R., Kowalczyk, E.A., O'Farrell, S.P., Waterman, L.J., Hirst, A.C., Wilson, S.G., Collier, M.A., Watterson, I.G., Elliott, T.I., 2002. The CSIRO Mk3 Climate System Model, CSIRO Atmo. CSIRO, Australia.

Gray, J.S., Dautel, H., Estrada-Peña, A., Kahl, O., Lindgren, E., 2009. Effects of climate change on ticks and tick-borne diseases in europe. Interdiscip. Perspect. Infect. Dis. 2009, 593232.

Guerra, M., Walker, E., Jones, C., Paskewitz, S., Cortinas, M.R., Stancil, A., Beck, L., Bobo, M., Kitron, U., 2002. Predicting the risk of Lyme disease: habitat suitability for Ixodes scapularis in the north central United States. Emerg. Infect. Dis. 8, 289–297. http://dx.doi.org/10.3201/eid0803.010166.

Haines, A., Kovats, R.S., Campbell-Lendrum, D., Corvalan, C., 2006. Climate change and human health: impacts, vulnerability, and mitigation. Lancet 367, 2101–2109 http://dx.doi.org/10.1016/S0140-6736(06)68933-2.

Harrus, S., Baneth, G., 2005. Drivers for the emergence and re-emergence of vector-borne protozoal and bacterial diseases. Int. J. Parasitol. 35, 1309–1318.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25, 1965–1978. http://dx.doi.org/10.1002/joc.1276.

Hosking, J., Campbell-Lendrum, D., 2012. How well does climate change and human health research match the demands of policymakers? A scoping review. Environ. Health Perspect. 120, 1076–1082. http://dx.doi.org/10.1289/ehp.1104093.

Jaenson, T.G.T., Hjertqvist, M., Bergström, T., Lundkvist, A., 2012. Why is tick-borne encephalitis increasing? A review of the key factors causing the increasing incidence of human TBE in Sweden. Parasites Vectors 5, 184.

Jaenson, T.G.T., Lindgren, E., 2011. The range of Ixodes ricinus and the risk of contracting Lyme borreliosis will increase northwards when the vegetation period becomes longer. Ticks Tick Borne Dis. 2, 44–49.

Jones, P., Thornton, P., 2013. Generating downscaled weather data from a suite of climate models for agricultural modelling applications. Agric. Syst. 114, 1–5.

Kalluri, S., Gilruth, P., Rogers, D., Szczur, M., 2007. Surveillance of arthropod vector-borne infectious diseases using remote sensing techniques: a review. PLoS Pathog. 3, 1361–1371. http://dx.doi.org/10.1371/journal.ppat.0030116.

Knap, N., Durmisi, E., Saksida, A., Korva, M., Petrovec, M., Avsic-Zupanc, T., 2009. Influence of climatic factors on dynamics of questing Ixodes ricinus ticks in Slovenia. Vet. Parasitol. 164, 275–281.

Kovats, R.S., Campbell-Lendrum, D.H., McMichael, A.J., Woodward, A., Cox, J.S., 2001. Early effects of climate change: do they include changes in vector-borne disease? Philos. Trans. R. Soc. Lond. B. Biol. Sci. 356, 1057–1068.

Lindquist, L., Vapalahti, O., 2008. Tick-borne encephalitis. Lancet 371, 1861–1871.

Massad, E., Coutinho, F.A.B., Lopez, L.F., da Silva, D.R., 2011. Modeling the impact of global warming on vector-borne infections. Phys. Life Rev. 8, 169–199.

McMichael, A.J., Lindgren, E., 2011. Climate change: present and future risks to health, and necessary responses. J. Intern. Med. 270, 401–413. http://dx.doi.org/10.1111/j.1365-2796.2011.02415.x.

Mills, J.N., Gage, K.L., Khan, A.S., 2010. Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. Environ. Health Perspect. 118, 1507–1514.

Morin, C.W., Comrie, A.C., Ernst, K., 2013. Climate and dengue transmission: evidence and implications. Environ. Health Perspect. 121, 1264–1272. http://dx.doi.org/10.1289/ehp.1306556.

Nikulin, G., Kjellström, E., Hansson, U., Strandberg, G., Ullerstieg, A., 2011. Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations. Tellus A 63, 41–55. http://dx.doi.org/10.1111/j.1600-0870.2010.00466.x.

Parks, C.G., Bernier, P., Bytnerowicz, A., Hånell, B., Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manag. 259, 698–709.

Patz, J.A., Campbell-Lendrum, D., Holloway, T., Foley, J.A., 2005. Impact of regional climate change on human health. Nature 438, 310–317. http://dx.doi.org/10.1038/nature04188.

Randolph, S.E., 2013. Is expert opinion enough? A critical assessment of the evidence for potential impacts of climate change on tick-borne diseases. Anim. Health Res. Rev. 14, 133–137. http://dx.doi.org/10.1017/S1466252313000091.

Roiz, D., Neteler, M., Castellani, C., Arnoldi, D., Rizzoli, A., 2011. Climatic factors driving invasion of the tiger mosquito (*Aedes albopictus*) into new areas of Trentino, northern Italy. PLoS One 6, e14800.

Ron, S.R., 2005. Predicting the Distribution of the Amphibian Pathogen Batrachochytrium dendrobatidis in the New World1. Biotropica 37, 209–221. http://dx.doi.org/10.1111/j.1744-7429.2005.00028.x.

Scachetti-Pereira, R., Stockwell, D., 2002. DesktopGarp.

Semenza, J.C., Menne, B., 2009. Climate change and infectious diseases in Europe. Lancet Infect. Dis. 9, 365–375.

Semenza, J.C., Suk, J.E., Estevez, V., Ebi, K.L., Lindgren, E., 2012. Mapping climate change vulnerabilities to infectious diseases in Europe. Environ. Health Perspect. 120, 385–392.

Stockwell, D., Peters, D., 1999. The GARP modelling system: problems and solutions to automated spatial prediction. Int. J. Geogr. Inf. Sci. 13, 143–158.

Süss, J., 2011. Tick-borne encephalitis 2010: epidemiology, risk areas, and virus strains in Europe and Asia—an overview. Ticks Tick Borne Dis. 2, 2–15.

Sutherst, R.W., 2004. Global change and human vulnerability to vector-borne diseases. Clin. Microbiol. Rev. 17, 136–173.

Thomas, P., Swaminathan, A., Lucas, R.M., 2012. Climate change and health with an emphasis on interactions with ultraviolet radiation: a review. Glob. Chang. Biol. 18, 2392–2405. http://dx.doi.org/10.1111/j.1365-2486.2012.02706.x.

Thuiller, W., Lavorel, S., Araújo, M.B., Sykes, M.T., Prentice, I.C., 2005. Climate change threats to plant diversity in Europe. Proc. Natl. Acad. Sci. U. S. A. 102, 8245–-8250. http://dx.doi.org/10.1073/pnas.0409902102.

Yamana, T.K., Eltahir, E.A.B., 2013. Projected impacts of climate change on environmental suitability for malaria transmission in West Africa. Environ. Health Perspect. 121, 1179–1186. http://dx.doi.org/10.1289/ehp.1206174.

Zhang, Y., Bi, P., Hiller, J.E., 2008. Climate change and the transmission of vector-borne diseases: a review. Asia Pac. J. Public Health 20, 64–76.

Article III

Boeckmann, M., & Zeeb, H. (2014). **Using a social justice and health Framework to assess European climate change adaptation strategies.** *International Journal of Environmental Research and Public Health*, *11*(12), 12389–12411. doi:10.3390/ijerph111212389

Int. J. Environ. Res. Public Health **2014**, *11*, 12389-12411; doi:10.3390/ijerph111212389

OPEN ACCESS

International Journal of
Environmental Research and Public Health
ISSN 1660-4601
www.mdpi.com/journal/ijerph

Article

Using a Social Justice and Health Framework to Assess European Climate Change Adaptation Strategies

Melanie Boeckmann [1,2,*] and Hajo Zeeb [1]

[1] Department Prevention and Evaluation, Leibniz Institute for Prevention Research and Epidemiology-BIPS, Achterstr. 30, 28359 Bremen, Germany; E-Mail: zeeb@bips.uni-bremen.de

[2] Center for Social Policy Research, University of Bremen, Mary-Somerville-Str. 5, 28359 Bremen, Germany

* Author to whom correspondence should be addressed;
E-Mail: melanie.boeckmann@bips.uni-bremen.de; Tel.: +49-421-218-58545.

External Editor: Paul B. Tchounwou

Received: 1 October 2014; in revised form: 24 November 2014 / Accepted: 25 November 2014 / Published: 28 November 2014

Abstract: Climate change puts pressure on existing health vulnerabilities through higher frequency of extreme weather events, changes in disease vector distribution or exacerbated air pollution. Climate change adaptation policies may hold potential to reduce societal inequities. We assessed the role of public health and social justice in European climate change adaptation using a three-fold approach: a document analysis, a critical discourse analysis of a subgroup of strategies, and a ranking of strategies against our social justice framework. The ranking approach favored planning that includes various adaptation types, social issues and infrastructure changes. Themes on values identified in the five subgroup documents showed that risks are perceived as contradictory, technology is viewed as savior, responsibilities need to be negotiated, and social justice is advocated by only a few countries. Of 21 strategy documents assessed overall, those from Austria, England and Sweden received the highest scores in the ranking. Our qualitative assessment showed that in European adaptation planning, progress could still be made through community involvement into adaptation decisions, consistent consideration of social and demographic determinants, and a stronger link between infrastructural adaptation and the health sector. Overall, a social justice framework can serve as an evaluation guideline for adaptation policy documents.

Keywords: climate change; climate change adaptation; policy analysis; discourse analysis; social justice; public health; social determinants of health; Europe

1. Introduction

1.1. Climate Change May Put Health at Risk

Climate change is a reality and may put human health at risk [1–3]. Projected climate change impacts include an increased frequency and intensity of heat waves and other extreme weather events, changes in disease vector and pollen distribution, or exacerbated air pollution [1,4,5]. Adverse health effects of climate change may include injuries and death following storms or floods, heat stroke and cardio-respiratory disease aggravation during extreme temperature events, an increased risk of infections and allergies, and higher skin cancer risks from increased UV exposure [1,5,6]. Governments in Europe thus face the need to prepare for these challenges, as has been supported by the Parma Declaration on Environment and Health in 2010 [7–9]. The term climate change adaptation describes measures undertaken to adjust to effects of climate, seeking to reduce harm and seize beneficial opportunities [10].

Adaptation has been described as a decision-making process that relies on effective governance [11]. In line with this definition, adaptation can be viewed as a task for all sectors and is not limited to environmental protection. Among previously identified climate change adaptation approaches, the following have been mentioned as promising for health protection: (1) monitoring and research, (2) consideration of demographic and social determinants, (3) community involvement, (4) early warning systems and emergency plans, (5) cross-sectoral efforts, and 6) infrastructural changes [12–16]. An integrated approach consisting of several of these measures has been described as more likely to protect health, regardless of the type of climate change impact [17,18].

1.2. Why a Social Justice Framework for Assessing European Climate Change Adaptation Strategies?

We assessed a sample of European climate change adaptation strategies with a framework informed by social justice concerns. Climate policy is subject to negotiations among priorities, perception and normative thinking [19]. Human health is but one of the concerns of climate-related policymaking. Yet, from a public health point of view, it seems odd that environmental protection should occur without explicit links to health, as the environment strongly influences health itself [20,21]. In addition, public health research has long been aware of the influence social environments have on human health [22].

Climate change affects human health not only directly but also indirectly through putting pressure on existing inequities and social determinants. Climatic changes have been linked to increased gender inequity [23,24], social disruption and forced cultural "re-inventions" [25]. Human health is doubly affected by climate change, once through direct effects on climate-related injuries and illness, and a second time through changes to socio-economic and cultural determinants of health [26,27]. The term "double exposure" [26] additionally implies that some population groups are twice burdened under a

changing climate: first from existing inequities, and additionally through new risks imposed. Viewed through this lens, climate change adaptation becomes a tool with which not only the outcomes of climatic changes can be targeted, but which may assist in addressing social determinants of ill health. As such, climate adaptation may contribute to advancing social justice. Social justice matters because it lies at the heart of public health as a discipline [28], and can contribute to health protection [22].

Social and natural environment are difficult to separate: the complex interaction of factors contributing to health have led to the concept of "ecological public health" [29]. As social and cultural dimensions influence susceptibility to climate change related health effects [25,30–32], increased vulnerability to environmental risks as a consequence of climatic changes has been framed as an environmental health and justice issue [33–36].

An assessment of European climate change adaptation can profit from contrasting strategies against a social justice framework that is based on the understanding that:

- Unequally distributed social determinants of health create a situation of inequity among European populations [22];
- Climate change will exacerbate existing health risks [5];
- Adaptation aims to prevent negative impacts of climate change [37], and
- Adaptation measures can support health equity through targeting these social determinants of health.

As the official European climate change adaptation strategy also explicitly calls for the integration of social factors into adaptation activities [38], we consider a social justice framework an appropriate and useful concept to assess current European adaptation efforts.

2. Methods

The aim of our study was to assess the health protection potential of selected European climate change adaptation strategies from a critical policy appraisal perspective. Our approach was three-fold: a document analysis on recognized impacts and supported adaptation types of all 21 included strategy papers, a critical discourse analysis identifying themes on value statements of a subgroup of six strategies selected for their inclusion of social justice concerns during a keyword search selection process, and finally a ranking exercise of strategies within a health-focused social justice framework.

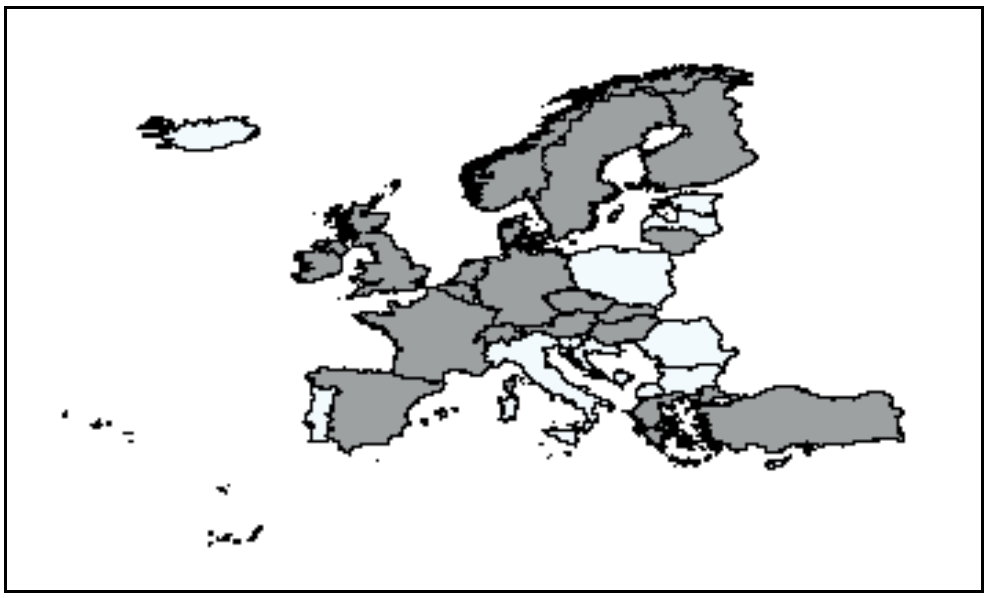
2.1. Document Analysis

A narrative review and document analysis of 21 European national adaptation strategies from 19 countries was conducted. We reviewed national adaptation strategies as specified on the European Environmental Agency (EEA) and European Commission (EC) joint website CLIMATE-ADAPT [39], complemented by an online search. The climate-adapt database is a useful source, because the European Environmental Agency aims at providing a comprehensive overview over all member states' strategy approaches and has been included in the European Climate Change Adaptation Strategy [38]. To inquire about draft strategies published in English, we contacted countries with an adaptation strategy under development. The website CLIMATE-ADAPT lists 18 of 32 European countries with an adopted national adaptation strategy as of August 2014 [39]. These countries are Austria [40],

Belgium [41], Denmark [42], Finland [43], France [44], Germany [45], Hungary [46], Ireland [47], Lithuania [48], the Netherlands [49], Portugal, Spain [50], Sweden [51], Switzerland [52], Turkey [53], and the United Kingdom [54–56]. Within the United Kingdom, Wales [54], Scotland [55] and England [56] provided individual strategies. The online search retrieved the Czech Republic's national adaptation strategy [57] and a Norwegian report [58] on climate change adaptation. Slovakia only provided a background document via personal communication as the official strategy is still being developed. The Bank of Greece provided a general report on impacts and adaptation measures [59].

Eight country strategy documents had to be excluded from analysis: Slovenia's strategy document covers only the forest and agriculture sector. Estonia, Latvia and Italy are currently developing national strategies. Romania, Poland, Bulgaria and Portugal did not provide an English-language version of their strategies and had to be excluded from analysis. Figure 1 shows a map of the countries included in our assessment [60].

Figure 1. Map of European countries included in the study.



Notes: Documents from 19 countries (three from the UK) were included in this study. These countries are marked in dark color. © Eurogeographics [60] for the administrative boundaries.

The search term human health was entered into each adaptation strategy document to assess whether or not adaptation takes place specifically in the health sector. With the aim of covering specific vulnerabilities related to age, migration, socio-economic disadvantages and gender [5,22], the following keywords were used in a second search within documents: social, socio* (* = allowing for all possible endings of the word), justice, fair, disadvantage, elder*, migra* (for migration, migrant, migrate), demograph*, divers* (except biodiversity), and gender. Sampling of strategy documents was driven by two considerations: First, we were interested in the framing of social determinants of climate change vulnerability in the official national document. Thus we excluded all documents that did not touch upon these issues. Second, we included only strategies in the subsample that contained the keywords fairness or justice.

We are aware that an *absence* carries meanings of its own. However, for the purposes of this research project, these absences of social justice consideration in strategies led to a lower ranking of the strategy and were not analyzed further. Six strategy documents from Austria, England, Finland, Greece, Sweden and Wales were included in our subgroup. The strategy texts were closely read and coded for themes stating values in MaxQDA software using a critical discourse analysis (CDA) approach influenced by van Dijk [61] and Fairclough and Fairclough [62].

2.2. Ranking of Country Strategies against the Social Justice Framework

Our ranking approach is based on adherence to the social justice framework with additional preference for infrastructural adaptation [63].

Bittner *et al*. [64] proposed a formula for ranking European heat warning systems. They assigned a value between 0 and 2 for stage of development of sub-parts of a heat warning system and added 25% to this partial score in cases where evaluation of the system took place. We propose an altered ranking method that takes into account:

- The high relevance of changes in social determinants of health under climate change [65], and
- The potential for successful health protection expected from structural adaptation [5].

Thus we argue for a higher weighting of those strategy documents that fare best when situated within the social justice framework. We assigned one point for each type of adaptation included in a national strategy. This is based on comprehensiveness of strategic approaches as our preferred concept for national adaptation efforts [66]. Subsequently, we added percentages to the partial scores as a weighting mechanism: 25% of the partial score for those documents explicitly addressing social justice and fairness (keyword search), 20% of the partial score to those documents addressing migration and demographic changes, two major drivers of structural health inequities [67,68], and 15% of the partial score to those including structural adaptation.

2.3. Critical Discourse Analysis Methodology

The goal of this discourse analysis was to analyze themes surrounding social issues and climate change adaptation that emerged from the texts. What is discourse analysis? It "involves the use of language data as evidence of social phenomena, theorizing language as communication, practice or selective constructions derived from accrued social meanings" ([69], p. 27). The textual data used for this analysis was selected from the pool of all 21 national adaptation strategies in this project as specified above. We first identified six strategy documents that discussed justice and social or cultural aspects of climate change and adaptation through a keyword search. Only documents containing the keywords justice or fairness and additionally migration or demographic changes were included in the subsample. In a second step, topics and value themes in these documents were analyzed following methods proposed by van Dijk [61] and Fairclough and Fairclough [62]. These methods are: close reading of the text, identification of topics and identification of themes related to values through an iterative process of coding, and memoing about these codes.

Fairclough and Fairclough [62] are interested in the power relations that drive the production of texts, using CDA to make conflicts and inequities visible [70]. Wodak and van Dijk stress the

importance of context for analysis purposes [61,70]. Context exceeds the text itself and extends into socio-political realms [70]. This understanding makes van Dijk's framework valuable for climate change studies: it has repeatedly been argued that the social context influences vulnerability, resilience and susceptibility to adverse effects of climatic changes [25,71]. Both approaches openly admit to having a political agenda, namely that of exposing mechanisms of social structures and identifying injustices [70].

Critical discourse theorists argue that knowledge can have different versions, some of which are accepted as truths and can be used to advance certain groups over others [69]. According to van Dijk [72], acceptance relies on access to dissemination of knowledge, for instance to media outlets. Official national documents may be perceived as prestigious and result in or prescribe specific actions, thus shaping the future of adaptation in each country. Consequently, exclusion or inclusion of social issues conveys an important message.

"Meanings are constituted through what is done" ([69], p. 10), therefore these documents show meanings attributed to health and social issues in national climate change adaptation strategies through what they suggest is done (as adaptation), *and* through the language and terms they are using.

Following Van Dijk's approach [61], we searched for *topics* within texts to identify what a section of text represents, so that the principles behind the strategy documents could be elicited. In a second step, we identified *themes revolving around values*. Values play an important role in Fairclough and Fairclough's practical reasoning framework [62]. Fairclough and Fairclough describe "practical reasoning [as] reasoning concerning what to *do* " ([62], p. 35) (emphasis by the authors of this article). As this study aimed to assess climate change adaptation regarding its inclusion of and potential for health protection, the *actions* outlined in the strategy documents are of high interest. Processes of negotiation in climate change contexts have been discussed elsewhere [73,74] and are not part of this research project.

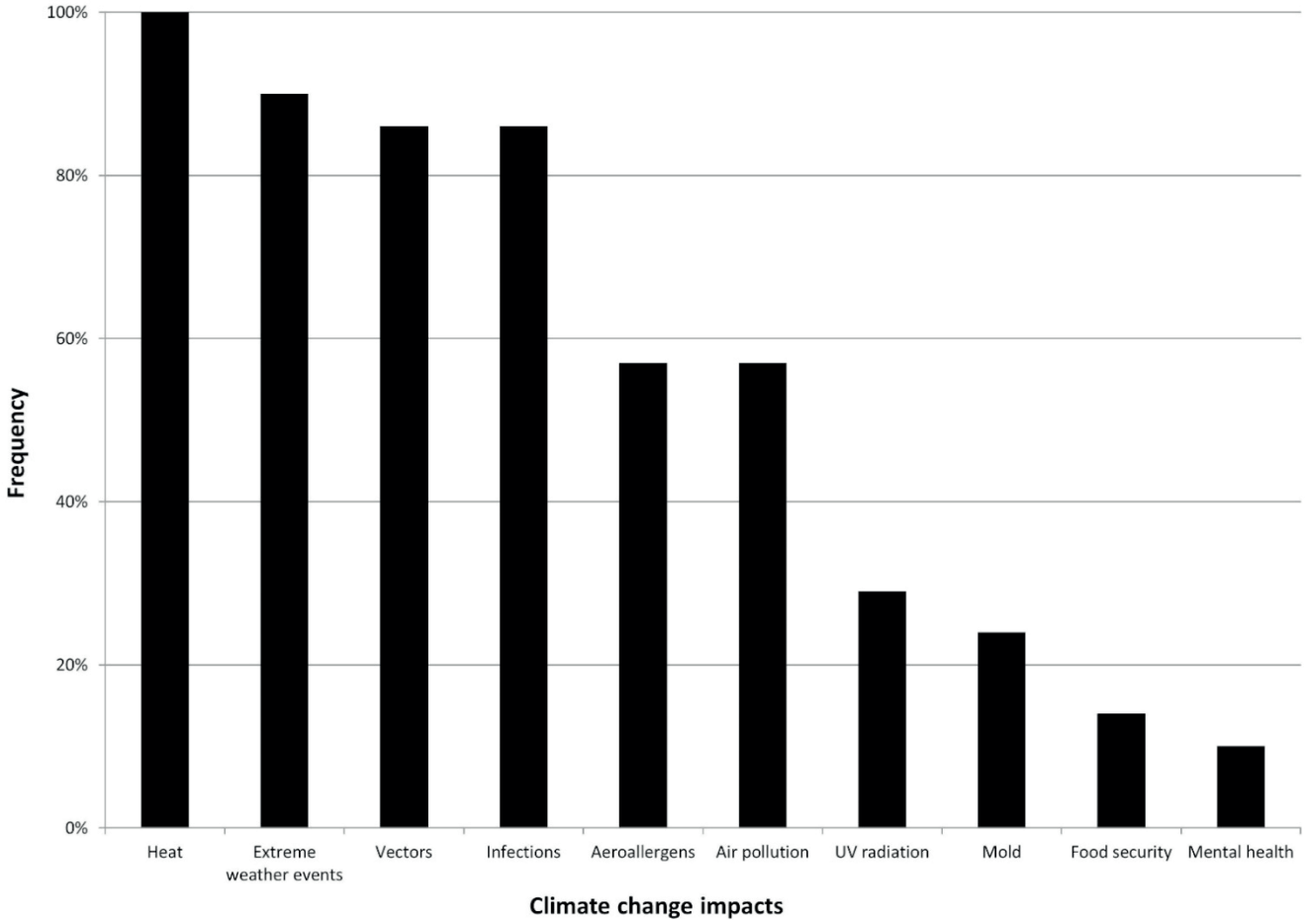
3. Results and Discussion

The document analysis revealed that all strategy documents include comments on health risks of climate change. Human health is a factor in the description of climate change impacts, adaptation options, or both.

3.1. Impacts of Climate Change on Health

Heat and extreme weather events play the largest role in European adaptation strategies, followed by infectious diseases (Figure 2). All 21 documents include heat, and 90% of documents discuss extreme weather events. Vector-, food- or water-borne infections are mentioned in 86% of the documents. Additional climate change impacts on health discussed are changes in aeroallergen distribution and exacerbation of air pollution (57% each), increase in UV radiation exposure (29%), mold development in houses (24%), food security (14%), and mental health issues (10%). Population displacement as results of climatic changes is only discussed in the Irish strategy.

Figure 2. Impacts of climate change on health discussed in strategy documents ranked by frequency of inclusion in strategy documents (more than one impact was mentioned in each document). Heat and extreme weather events were mentioned separately in the texts, as were vectors and other infections. Infections refer to food- and water-borne infections.



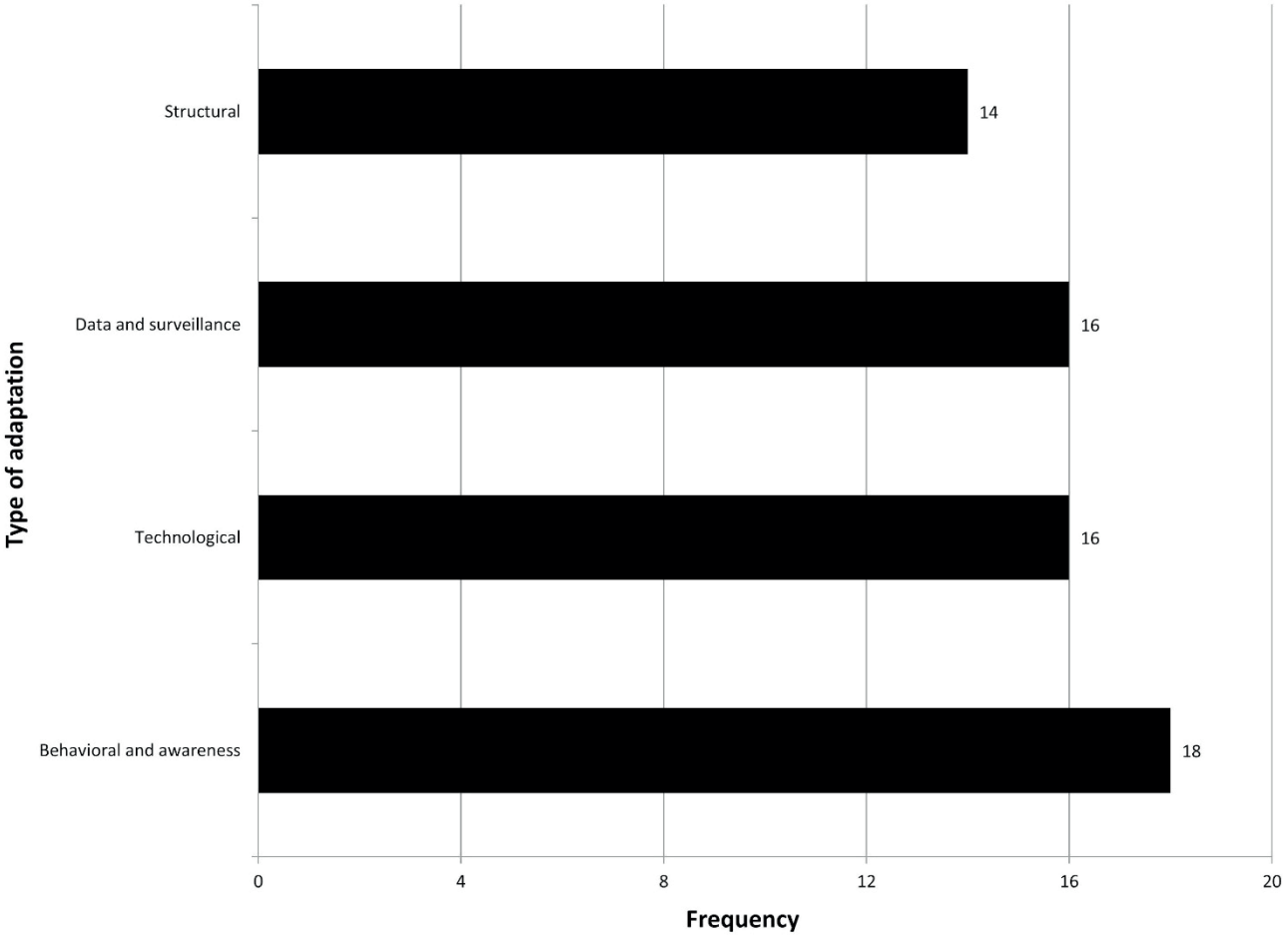
3.2. Adaptation Measures in European Strategy Documents

We categorized adaptation into four major types, based on a typology proposed by Balbus *et al.* [75]:

- Data and surveillance
- Technological adaptation, including emergency plans and warning systems
- Behavioral adaptation and awareness raising
- Infrastructural adaptation

When categorized according to type of adaptation, the most frequently cited adaptation type is awareness raising and education programs (18 documents), with technological adaptation and data/surveillance categories in 16 documents each (Figure 3). Infrastructural and engineering adaptation comes in last with 14 documents. Germany, Denmark, Hungary, and Turkey advocate vaccine development for emerging infectious diseases. Lithuania plans to strengthen health sector financing, and the Czech Republic stresses changes in European and national legislation as an additional strategy.

Figure 3. Types of adaptation proposed by strategy documents ranked by most frequent inclusion in strategy documents (more than one adaptation type was mentioned in each document).



Adaptation to health impacts is proposed by all 21 strategy documents. Specificity and comprehensiveness of the proposed adaptation measures vary between the strategies. Slovakia, for instance, focusses on raising awareness among medical personnel and on implementation of a warning system. Turkey, on the other hand, includes all four types of adaptation in its planning. Of interest are innovative, structural adaptation measures proposed by strategies, such as building publicly accessible water fountains in Austria, adding air conditioning to hospitals in Sweden, or strengthening the National Health Service in England. Mainstreaming climate change adaptation into all policies is suggested by Austria.

Impacts such as food security, linked to climate impacts on global agriculture, mold development in private housing, UV radiation exposure, exacerbated air pollution, and mental health impairments after extreme events are mostly excluded from the adaptation descriptions. England suggests public UV monitoring. It is unclear whether this results from prioritization of other health impacts or from difficulties creating an adaptation measure for these risks. These risks in particular require trans-sectoral and societal approaches.

Not all country strategy documents view climate change as a threat: Norway and the Czech Republic position themselves as well-prepared for climate change. Despite a common awareness of

climate change impacts and associated health risks, European adaptation programs differ in their assessment of potential consequences of these impacts.

The results of our document analysis show that adaptation measures for highly ranked risks such as extreme weather events, extreme temperatures and infectious diseases are persistently recommended in European national strategies. Beyond these common aims, however, varied levels of comprehensiveness occur between countries. These variations include both additional impacts recognized and adaptation measures proposed. A second variation can be found in the documents' treatment of social issues, as discussed in the following paragraphs.

3.3. Ranking of Country Documents

Table 1 shows the ranking of the examined European national strategies against the social justice framework. The baseline partial score was calculated from number of adaptation types included; the more different types, the more comprehensive we judged the strategy to be. To this partial score we added weighting for social justice. Owing to this approach, Wales, with fewer adaptation types, did not rank in the upper two thirds despite its commitment to promoting fairness and equity.

Country strategies with the highest score are Austria, England and Sweden. These documents not only recommended all four types of adaptation measures but were additionally committed to promoting social justice, taking into account social determinants, and gained extra points for the inclusion of infrastructural adaptation. Six country documents rank in second place. In this ranking, we find Denmark, Lithuania and Scotland with a score below 2.5, followed by Ireland and the Netherlands.

3.4. Discourse Analysis of Subgroup Articles

Results of the CDA are represented as four value themes: (a) the cautionary principle in light of uncertainties, (b) responsibility, (c) technology as savior and (d) social justice and gender equity.

3.4.1. The Cautionary Principle in Light of Uncertainties

Uncertainties are inherent to climate projections and lie at the heart of climate adaptation projects. Certain risks to human health have been described as generally applicable (such as extreme temperature, extreme weather events, and vector distribution changes, see also introduction of this article). Yet this universality of risks is handled differently among the examined countries. Heat to Finland [43] is both a risk and not a risk: a contradiction. Compare the following statements as an example:

"Excess mortality is significantly higher in extremely cold temperatures than during periods of intense heat, and extremely cold temperatures are estimated to become less common," ([43], p. 157)

and:

"[…][H]ealth impacts due to hot weather can be expected at lower temperatures in Finland compared to Central Europe" ([43], p. 157).

Here we observe an ambiguity in confronting an increase in extreme heat events.

Table 1. Ranking results.

Country	Type of Adaptation				Partial Score	Social Justice	Social Issues Migration and Demographic Change	Structural Adaptation	Total Score
	Data/Surveillance	Technological	Behavioral	Structural		Add 25%	Add 20%	Add 15%	
Austria	1	1	1	1	**4**	1	0.8	0.6	**6.4**
UK: England	1	1	1	1	**4**	1	0.8	0.6	**6.4**
Sweden	1	1	1	1	**4**	1	0.8	0.6	**6.4**
Belgium	1	1	1	1	**4**	0	0.8	0.6	**5.4**
Czech Republic	1	1	1	1	**4**	0	0.8	0.6	**5.4**
France	1	1	1	1	**4**	0	0.8	0.6	**5.4**
Germany	1	1	1	1	**4**	0	0.8	0.6	**5.4**
Norway	1	1	1	1	**4**	0	0.8	0.6	**5.4**
Turkey	1	1	1	1	**4**	0	0.8	0.6	**5.4**
Finland	1	1	0	1	**3**	0.75	0.6	0.45	**4.8**
Greece	1	1	0	1	**3**	0.75	0.6	0.45	**4.8**
Hungary	0	1	1	1	**3**	0	0.6	0.45	**4.05**
Switzerland	1	0	1	1	**3**	0	0.6	0.45	**4.05**
Slovakia	0	1	1	1	**3**	0	0	0.45	**3.45**
Spain	1	1	1	0	**3**	0	0	0	**3**
UK: Wales	0	1	1	0	**2**	0.5	0.4	0	**2.9**
Denmark	1	0	1	0	**2**	0	0.4	0	**2.4**
Lithuania	1	0	1	0	**2**	0	0.4	0	**2.4**
UK:Scotland	1	0	1	0	**2**	0	0.4	0	**2.4**
Ireland	0	1	1	0	**2**	0	0	0	**2**
Netherlands	0	0	0	0	**0**	0	0	0	**0**

A similar debate occurs regarding vector-borne diseases: On the one hand:

"the climate has not been decisive for the occurrence of these communicable diseases or the emergence of a pathogen cycle," ([43], pp. 158–159),

yet at the same time the Finish strategy suggest that ticks or bank voles may find more favorable conditions as a result of climate change ([43], p. 160).

These findings suggest that that careful consideration is of high value in Finland, with the goal of targeting the *right risks.* Overall, the contradictory nature of temperature-related risks does not deter Finland from acting: we would call this an adherence to the *precautionary principle*. This is illustrated in the following statement on reviews as part of an adaptation strategy:

"[these are] the foundation for evaluating any no-regrets measures whose implementation would benefit the sector or target groups regardless of climate change" ([43], p. 11).

Benefits regardless of climate change as the ultimate justification for adaptation fits well into a precautionary framework.

This theme has also been picked up by Sweden [51]:

"The warmer climate will affect health and lead to more deaths due to heat waves and increased spread of infection" ([51], p. 11),

later followed by:

"*Few cold snaps produce positive health effects"* ([51], p. 430).

Acknowledging uncertainties leads to precautious activities in climate change adaptation. Policy acts in the face of scientific uncertainties, a theme that may be useful for social justice action among the lines of "better safe than sorry".

3.4.2. Who is Responsible for Adaptation?

A second theme prominent in the examined documents is global responsibility. European countries highlight contrasts between their positions and those of countries of the Global South, and formulate consequences of that positioning. For instance, Sweden [51] argues from a legal standpoint:

"According to article 4.4 of the Climate Convention (UNFCCC), the industrialised countries (Annex I countries) should support the developing countries that are most vulnerable to climate change" ([51], p. 456).

Wales [54] takes this theme further and acknowledges that as an industrialized country in the Global North:

"we are responsible for a much larger proportion of global emissions because of the goods and services we consume but which are made elsewhere" ([54], p. 15).

As a consequence, Wales proposes that:

"Sharing experience and learning on this challenging agenda is vital and we are committed, through our Wales for Africa programme, to working with communities in other parts of the world in responding to climate change" ([54], p. 19).

England [56] similarly states that:

"the government continues to support programmes helping the poorest and most vulnerable people in climate change 'hot-spots', as well as identifying and refining tools which are cost-effective and sustainable" ([56], p. 11).

Such commitment to "help" could also be interpreted as "othering" Africa and possibly additional countries in the Global South [76]. By creating a dichotomy of rich versus poor, technologically advanced versus helpless in the face of climate change, these European strategy documents may cement inequities rather than promote social justice. This interpretation is supported by a common perception that immigration is a result of climatic changes. The Austrian strategy states that:

"studies on development mechanisms of migratory movements to Austria and Europe should be initiated to reduce or deal with possible migration"(translated from German by the authors)" ([40], p. 91).

Greece [59] *"has already received large numbers of immigrants, and these numbers will increase significantly in future as the flow of environmental refugees increases"* ([59], p. 463),

and Sweden [51] concurs:

"Sweden will also experience an increased number of cases of infectious diseases where the infection is contracted overseas due to increased global infection pressure" ([51], p. 443).

Immigration to European countries is discussed in the strategies and represents awareness about global migratory patterns.

The link between poverty and effects of climate change is generally acknowledged, leading to the above mentioned referral to Europe's responsibility to mitigate climate change and support lower income countries. Incorporating environmental agreements into aid and development is Europe's answer to these global inequities. Again, this approach has its shortcomings: within the UNFCCC negotiation processes, the least developed countries need to combine mitigation efforts and related expenses with national development goals [77]. Future research could examine this issue further and assess the implications between causing environmental harm first and subsequentlyoffering the "gift" of support to those being harmed in the process [78].

3.4.3. Technology as Savior

Within the Welsh, English and Finnish strategy documents, technological adaptation is highlighted as the best solution, particularly for flood risks or in the shape of heat warning systems. As a value statement, inherent to technological solutions to climate change is solvency, *i.e.*, being in a financially secure situation.

Finland [43] stresses that:

"development of solvency is crucial to human health", and *"[t]he industrial-technical culture […] is capable of protecting human beings in various ways"* ([43], p. 231).

England [56] agrees:

"Development and economic progress will, in many cases, be the most effective way of helping countries to adapt, as well as helping to create stability" ([56], p. 11),

and proposes the development of new technology. Wales [54] is particularly ambitious in linking technology and climate change:

"Ensuring that our approach to R&D, technology, innovation and skills help Wales gain maximum benefit from climate change related business and research" ([54], p. 6).

A technocratic solution also links back to the previous theme of responsibility and "othering": while European countries are in the position to afford high-tech alternatives, the majority of countries might not be. A consequence could be a commitment to giving these technologies to the Global South, the implications of which have been discussed above. Beyond adaptation, technology plays an important role for mitigation with its promise of energy efficiency and "a new green deal [56]." In England and Wales, technology in adaptation is thus portrayed as promising economic opportunity, not only as a means to an end. The examined strategies value solvency, technological advancement and co-benefits of adaptation. The Greek document in particular points out financial gains as motivation for adaptation.

3.4.4. Social Justice and Gender Equity

The theme of social justice is intricately linked to antidiscrimination, gender equity, fairness, and protecting cultural diversity. Austria and Wales specifically mention justice as a value and a goal.

Related to the issue of global responsibility, but equally applicable to the national context, Wales [54] acknowledges:

"Climate change is a social justice issue. Globally, and here in Wales, we can expect its impacts to disproportionately affect those least able to manage them and who are, at the same time, least responsible for causing the problem" ([54], p. 16).

A clearly stated goal of the Welsh strategy is to:

"[…] ensure that our policies to tackle climate change also promote social justice" ([54], p. 16).

Similarly, Austria [40] writes that policy development should weigh benefits and harms:

"stratified by different population groups and gender" (translated from German by the authors) ([40], p. 44).

Regarding gender equity, the Austrian document proposes a commitment to enabling women to participate in adaptation processes:

"It is important that even within climate change adaptation measures women receive equal opportunities to participate, create and decide in societal processes"(translated from German by the authors) ([40], p. 45).

However, neither strategy gives recommendations on specific actions to achieve social justice.

4. Discussion

4.1. Europe is Aware of Climate Change Health Impacts

In general, protecting human health is one goal of European climate change adaptation strategies. The impact assessments are in line with research results on projected impacts of climate change [1]. This is not surprising given that the strategy documents regularly refer to published research.

Our results confirm those of previous studies on human health as a vulnerable sector in national European adaptation strategies [66,79]. However, the link between health protection and climate change adaptation in other sectors is not always explicit. For instance, the Netherlands plans for flood risks, yet their strategy does not discuss health implications of structural adaptation.

Heat warning systems have recently been the subject of increased research activity [16,64], yet the national documents rarely described heat warning systems as specific projects. A possible explanation for this discrepancy may lie in national versus regional climate change adaptation approaches. A second reason might be the distribution of responsibilities between departments. And finally, heat warning systems are concrete outputs of adaptation projects, whereas national strategy documents serve the purpose of outlining a country's overall approach to adaptation, specifying concrete actions in add-on documents. This has been done in Austria, Germany and France, for example, where action plans support the national strategies.

4.2. Social Determinants of Health Play a Role in European Climate Change Adaptation

Consideration of social and demographic determinants has been identified as an important aspect of climate adaptation [80]. In the examined adaptation strategies, social and socio-economic factors were considered in scenario design or impact analysis. Austria, Wales, England and Turkey acknowledged gender as a category that might contribute to (further) inequities. As we have seen in the discourse analysis, responsibility as a theme illustrates awareness of the interconnectedness of European countries with countries in the Global South. The role of social determinants of health is thus not limited to the local but extends beyond European borders. This may influence decision-making processes. It would be interesting to contrast these environmental strategies with official development aid documents and practices to see if values and goals are aligned between sectors. This might also shed light on whether solvency, a highly rated goal in England and Greece, extends to increasing solvency in the Global South. We also find it of interest that the precautionary principle plays such a large role in the discussion about climate change adaptation measures and human protection.

Six European adaptation strategies explicitly address climate change as a social justice issue, and 17 documents show awareness of migration and demographic changes as risk factors of climate change (Table 1). These results might be interpreted as promising; whether actual measures to reduce structural inequities will be taken remains to be seen. The large number of documents including proposals for structural adaptation might bear potential for health protection, as structural disease prevention programs have also been described as effective in environmental health [81]. Our novel ranking approach allowed us to combine assessments of justice and health protection potentials. However, any ranking has an inherent bias towards certain variables: the Czech Republic fared well in

the ranking, yet the entire strategy only discusses health in one paragraph. Any ranking results should therefore not replace an in-depth analysis of policy documents before drawing conclusions.

4.3. Weaknesses of European Strategies Persist

Our results show a gap between current knowledge on good practice adaptation for health and specific actions in health policy, confirming previous research [8,66,82]. Not all good practice advice from research has been incorporated into European adaptation design. There seems to be potential for improvement in linking health and infrastructure or planning, especially for the climate risks of flooding and extreme heat as these are highly relevant for urban design and for the health sector. Very little consideration has been given to community involvement. Most national strategies examined here do not yet adequately design approaches for the inclusion of communities or adaptation target populations. Wales is a positive exception, focusing on local adaptation efforts. Overall, further research into appropriate forms of *participatory* adaptation in Europe seems warranted. Such research designs could draw from results of community-based adaptation projects in developing countries [71,83].

A large number of European strategies are not yet accompanied by action plans, indicating further potential for an improved adaptive response. Systematic considerations of uncertainties associated with climate change adaptation, from climate models to national socio-economic development, are still missing [66]. Uncertainties play a prominent role in climate change discourses: from estimating impacts [84] to evaluating policy [85], what we cannot know about the future shapes current responses to climate change. Living with these uncertainties might require policymakers to rethink standard approaches to evidence-based policy.

Within the policy documents, possible co-harms and co-benefits to health of proposed adaptation strategies are rarely explored. Previous research has suggested that any adaptation measure could lead to unwanted negative effects on health, such as changing walking behavior through urban planning adjustments [86]. Both negative and positive effects of strategic measures could also be modelled, as has been done for mitigation strategies [87].

4.4. What Is Next for European Adaptation Strategies?

Within the climate and health research community, new concepts have been proposed. "Planetary health" [88] stresses the links between global environments and human health. If we assume such a large scale interdependency, strategies that only propose isolated individual adaptation measures might not be sufficient. As stated before, evidence for the effectiveness of specific measures is still missing, despite hints at potential effects of adaptation [89,90]. Instead, viewing adaptation policy as a larger, transformational effort has been suggested [91]. Karen O'Brien distinguishes between unintended and deliberate transformation, and defines it as "*[…] physical and/or qualitative changes in form, structure or meaning-making that can also include a psycho-social process*" [91]. Applied to European adaptation strategies, transformation could mean trans-sectoral approaches, long-term visions, innovative solutions, and designing policies aimed at structural changes. We have seen that the examined strategies propose technological innovations, "green deals" and even "cultural re-inventions," to borrow the term from Adger *et al.* [25]. Some ideas of transformational designs are already included in Europe's strategies, yet the term itself is not used.

4.5. Limitations

This study has several limitations. Only national strategies and draft national documents were included in the analysis. Individual cities or regions might have different strategies in place. Local adaptation is likely more capable of taking regional differences and needs into account [92]. However, national legislation plays an important role in encouraging and enabling regional agencies to pursue adaptation [92]. Several European countries are currently developing strategies not yet included in this study. Climate change adaptation is a work in progress, and keeping track of updated documents is challenging.

Documents without an English or German translation had to be excluded. Six of nine strategy documents excluded are from Central and Eastern European countries. Their national adaptation strategies might stress different approaches for health protection not covered here.

Using a social justice framework of course implies our normative approach to climate change adaptation. Our ranking method and selection of themes mirrors this normative understanding and may not necessarily reflect the aims of the policymakers who developed the strategies.

Recent studies have reviewed European heat wave warning systems [16,64], finding a larger number of warning strategies in place than mentioned in official national strategy documents. The reason for this omission in official national documents is unclear.

As we selected the strategies for the discourse analysis based on their discussion of social determinants, we are necessarily biased to detect reasons for an inclusion of said determinants rather than reasons for exclusion. Strategies without social determinants do not state reasons for the omission. We argue that the absence in itself carries a local meaning: it could be interpreted as perceived lack of relevance and/or political will to engage with these social aspects of climate change adaptation. Additionally, our assessment was necessarily based on the data sources we used. Other documents from the selected countries may lead to different conclusions.

5. Conclusions

A social justice framework can serve as an evaluation guideline for adaptation policy documents. We were able to show that the links between social determinants of health and a potential exacerbation of inequities under climatic changes are partially acknowledged in European countries.

Drawing from previous research into evaluation of adaptation, we have developed a theory-driven method to portray most promising strategy documents for health protection through foregrounding social justice, social determinants of health, and structural adaptation measures. Our results can contribute to strengthening the focus on human health and reduction of injustices in adaptation efforts.

In this article we have repeatedly pointed out the necessity to ground any adaptation actions for health protection in a socially responsible framework.

Our results suggest that European adaptation strategies are aware of climate risks, including adverse effects on health. A large number of European countries have made strides in preparing for climate change and combine two or more adaptation types to address these risks. This study complements a recent WHO survey on health action and climate change in Europe [8] by adding a social justice dimension and qualitative assessment. In European countries, progress could still be made through

community involvement into adaptation decisions, and consistent inclusion of social and demographic determinants. A stronger link between infrastructural adaptation and the health sector could be considered.

Acknowledgments

This study was partially supported by a University of Bremen and Leibniz Institute for Prevention Research and Epidemiology-BIPS joint dissertation scholarship for Melanie Boeckmann. The authors would like to thank Nataliya Makarova and Andrew N. McIntyre for critical readings of the manuscript and helpful comments. Two anonymous reviewers gave helpful suggestions.

Author contributions

Melanie Boeckmann designed the study, conducted the analyses and developed the manuscript. Hajo Zeeb suggested a ranking approach and co-wrote the manuscript. Both authors have read and approved the final version of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Confalonieri, U.; Menne, B.; Akhtar, R.; Ebi, K.L.; Hauengue, M.; Kovats, R.S.; Revich, B.; Woodward, A. Human health. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 391–431.
2. Barrett, J.R. Climate change mitigation: Assessing strategies that offer potential human health benefits. *Env. Heal. Perspect.* **2014**, *122*, doi:10.1289/ehp.122-A139.
3. World Health Organization. *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*; Hales, S., Kovats, S., Lloyd, S., Campbell-Lendrum, D., Eds.; World Health Organization: Geneva, Switzerland, 2014.
4. Füssel, H.-M. An updated assessment of the risks from climate change based on research published since the IPCC Fourth Assessment Report. *Clim. Change* **2009**, *97*, 469–482.
5. Smith, K.R.; Woodward, A.; Campbell-Lendrum, D.; Chadee, D.; Honda, Y.; Liu, Q.; Olwoch, J.; Revich, B.; Sauerborn, R. Human health: Impacts, adaptation and co-benefits. In *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., *et al*., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 709–754.
6. McMichael, A.; Montgomery, H.; Costello, A. Health risks, present and future, from global climate change. *BMJ* **2012**, *344*, doi:10.1136/bmj.e1359.

7. European Evironment Agency (EEA). *Urban Adaptation to Climate Change in Europe*; EEA Report 2/2012; European Environment Agency: Copenhagen, Denmark, 2012.
8. Wolf, T.; Martinez, G.S.; Cheong, H.-K.; Williams, E.; Menne, B. Protecting health from climate change in the WHO European region. *Int. J. Environ. Res. Public Health* **2014**, *11*, 6265–6280.
9. World Health Organization. Ministerial conference on environment and health parma declaration on environment and health. In *Fifth Ministerial Conference on Environment and Health: "Protecting children's health in a changing environment"*; World Health Organization Regional Office for Europe: Copenhagen, Denmark, 2010.
10. IPCC. IPCC Annex III: Glossary. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013; pp. 1447–1465.
11. Nelson, D.R.; Adger, W.N.; Brown, K. Adaptation to environmental change: Contributions of a resilience framework. *Annu. Rev. Environ. Resour.* **2007**, *32*, 395–419.
12. Ebi, K.L.; Lindgren, E.; Suk, J.E.; Semenza, J.C. Adaptation to the infectious disease impacts of climate change. *Clim. Change* **2013**, *118*, 355–365.
13. Kovats, R.S.; Kristie, L.E. Heatwaves and public health in Europe. *Eur. J. Public Health* **2006**, *16*, 592–599.
14. Wolf, J.; Adger, W.N.; Lorenzoni, I.; Abrahamson, V.; Raine, R. Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. *Glob. Environ. Chang.* **2010**, *20*, 44–52.
15. Semenza, J.C.; Suk, J.E.; Estevez, V.; Ebi, K.L.; Lindgren, E. Mapping climate change vulnerabilities to infectious diseases in Europe. *Environ. Health Perspect.* **2012**, *120*, 385–392.
16. Lowe, D.; Ebi, K.L.; Forsberg, B. Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. *Int. J. Environ. Res. Public Health* **2011**, *8*, 4623–4648.
17. Frumkin, H.; Hess, J.; Luber, G.; Malilay, J.; McGeehin, M. Climate change: The public health response. *Am. J. Public Health* **2008**, *98*, 435–445.
18. Costello, A.; Abbas, M.; Allen, A.; Ball, S.; Bell, S.; Bellamy, R.; Friel, S.; Groce, N.; Johnson, A.; Kett, M.; *et al.* Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet* **2009**, *373*, 1693–1733.
19. Urwin, K.; Jordan, A. Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. *Glob. Environ. Chang.* **2008**, *18*, 180–191.
20. O'Neill, M.S.; McMichael, A.J.; Schwartz, J.; Wartenberg, D. Poverty, environment, and health: The role of environmental epidemiology and environmental epidemiologists. *Epidemiology* **2007**, *18*, 664–668.
21. Prüss-Üstün, A.; Corvalán, C. *Preventing Disease through Healthy Environments. Towards an Estimate of the Environmental Burden of Disease*; World Health Organization: Geneva, Switzerland, 2006.

22. Marmot, M.; Allen, J.; Bell, R.; Bloomer, E.; Goldblatt, P. WHO European review of social determinants of health and the health divide. *Lancet* **2012**, *380*, 1011–1029.
23. European Institute for Gender Equality. *Gender Equality and Climate Change—Main Findings*; Publications Office of the European Union: Brussels, Belgium, 2012.
24. United Nations Development Program. *Resource Guide on Gender and Climate Change*; United Nations Development Program: New York, NY, USA, 2009.
25. Adger, W.N.; Barnett, J.; Brown, K.; Marshall, N.; O'Brien, K. Cultural dimensions of climate change impacts and adaptation. *Nat. Clim. Chang.* **2013**, *3*, 112–117.
26. O'Brien, K.L.; Leichenko, R.M. Double exposure: Assessing the impacts of climate change within the context of economic globalization. *Glob. Environ. Chang.* **2000**, *10*, 221–232.
27. Friel, S.; Hancock, T.; Kjellstrom, T.; McGranahan, G.; Monge, P.; Roy, J. Urban health inequities and the added pressure of climate change: An action-oriented research agenda. *J. Urban Health* **2011**, *88*, 886–895.
28. Gostin, L.O.; Powers, M. What does social justice require for the public's health? Public health ethics and policy imperatives. *Health Aff. (Millwood)* **2006**, *25*, 1053–1060.
29. Morris, G.P. Ecological public health and climate change policy. *Perspect. Public Health* **2010**, *130*, 34–40.
30. Vescovi, L.; Rebetez, M.; Rong, F. Assessing public health risk due to extremely high temperature events: Climate and social parameters. *Clim. Res.* **2005**, *30*, 71–78.
31. Harlan, S.L.; Declet-Barreto, J.H.; Stefanov, W.L.; Petitti, D.B. Neighborhood effects on heat deaths: Social and environmental predictors of vulnerability in Maricopa County, Arizona. *Environ. Health Perspect.* **2013**, *121*, 197–204.
32. Nielsen, J.Ø.; Reenberg, A. Cultural barriers to climate change adaptation: A case study from Northern Burkina Faso. *Glob. Environ. Chang.* **2010**, *20*, 142–152.
33. Sovacool, B.K. Adaptation: The complexity of climate justice. *Nat. Clim. Chang.* **2013**, *3*, 959–960.
34. Barrett, S. Local level climate justice? Adaptation finance and vulnerability reduction. *Glob. Environ. Chang.* **2013**, *23*, 1819–1829.
35. Morello-Frosch, R.; Zuk, M.; Jerrett, M.; Shamasunder, B.; Kyle, A.D. Understanding the cumulative impacts of inequalities in environmental health: Implications for policy. *Health Aff. (Millwood)* **2011**, *30*, 879–887.
36. Bowen, K.J.; Friel, S. Climate change adaptation: Where does global health fit in the agenda? *Global. Health* **2012**, *8*, doi:10.1186/1744-8603-8-10.
37. Adger, W.N.; Arnell, N.; Tompkins, E. Successful adaptation to climate change across scales. *Glob. Environ. Chang. A* **2005**, *15*, 77–86.
38. European Commission. *An EU Strategy on adaptation to climate change*; European Union: Brussels, Belgium, 2013.
39. European Union CLIMATE-ADAPT. European Climate Adaptation Platform. Available online: http://climate-adapt.eea.europa.eu/ (accessed 30 September 2014).
40. Bundesministerium für Land-und Forstwirtschaft Umwelt und Wasserwirtschaft. *Die österreichische Strategie zur Anpassung an den* Klimawandel; Government of Austria: Vienna, Austria, 2012.

41. Belgian National Climate Commission. *Belgian National Climate Change Adaptation Strategy*; Government of Belgium: Brussels, Belgium, 2010.
42. Danish Government. *Danish Strategy for Adaptation to a Changing Climate*; Government of Denmark: Copenhagen, Denmark, 2008.
43. Ministry of Agriculture and Forestry Finland. *Finland's National Strategy for Adaptation to Climate Change*; Government of Finland: Helsinki, Finland, 2005.
44. Ministère de l'Écologie du Développement durable des Transports et du Logement. *French National Climate Change Impact Adaptation Plan*; Government of France: Paris, France, 2011.
45. Federal Ministry for the Environment Nature Conservation and Nuclear Safety. *German Strategy for Adaptation to Climate Change*; The Federal Government of Germany: Bonn, Germany, 2008.
46. Hungarian Government. *National Climate Change Strategy 2008–2025*; Government of Hungary: Budapest, Hungary, 2008.
47. Department of the Environment Community and Local Government Ireland. *National Climate Change Adaptation Framework Building Resilience to Climate Change*; Government of Ireland: Dublin, Ireland, 2012.
48. Government of the Republic of Lithuania. *Resolution on the Approval of the National Strategy for the Implementation of the United Nations Framework Convention on Climate Change until 2012*; Government of the Republic of Lithuania: Vilnius, Lithuania, 2008.
49. Ministry of Housing, Spatial Planning and the Environment (VROM), Ministry of Transport, Public Works and Water Management (V&W), Ministry of Agriculture, Nature and Food Quality (LNV), Ministry of Economic Affairs (EZ),Association of Provincial Authorities (IPO), Association of Netherlands Municipalities (VNG), Association of Water Boards (UvW). *Make Room for the Climate. Initial Steps towards a National Adaptation Strategy*; Government of The Netherlands: Den Haag, The Netherlands, 2007.
50. Ministry of Environment and Rural and Marine Affairs Spain. *The Spanish National Climate Change Adaptation Plan*; Government of Spain: Madrid, Spain, 2008.
51. Swedish Commission on Climate and Vulnerability. *Sweden Facing Climate Change: Threats and Opportunities.*; Government of Sweden: Stockholm, Sweden, 2007.
52. Bundesamt für Umwelt. *Anpassung an den Klimawandel in der Schweiz: Handlungsfelder. Erster Teil der Strategie des Bundesrates*; Government of Switzerland: Bern, Switzerland, 2012.
53. T.R. Ministry of Environment and Urbanization. *Turkey' s National Climate Change Adaptation Strategy and Action Plan*; Government of Turkey: Ankara, Turkey, 2011.
54. Welsh Assembly Government. *Climate Change Strategy for Wales*; Welsh Assembly Government: Cardiff, Wales, 2010.
55. The Scottish Government. *Scotland' s Climate Change Adaptation Framework: Health and Wellbeing Sector Action Plan*; The Scottish Government: Edinburgh, Scotland, 2007; pp. 1–16.
56. Department for Environment Food and Rural Affairs England. *The National Adaptation Programme: Making the Country Resilient to a Changing Climate*; London, UK, 2013.
57. Ministry of the Environment Czech Republic. *National Program to Abate the Climate Change Impacts in the Czech Republic*; Government of Czech Republic: Prague, Czech Republic, 2004.

58. Committee to the Ministry of the Environment. *Adapting to a Changing Climate. Official Norwegian Reports NOU 2010:10*; Government of Norway: Oslo, Norway, 2010.
59. Climate Change Impacts Study Committee. *The Environmental, Economic and Social Impacts of Climate Change in Greece*; Government of Greece: Athens, Greece, 2011.
60. EuroGeographics Europe Administrative Boundaries. Available online: http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/administrative_units_statistical_units_1 (accessed 15 September 2014).
61. Van Dijk, T. Multidisciplinary CDA: A plea for diversity. In *Methods of critical discourse analysis*; Wodak, R., Meyer, M., Eds.; Sage: London, UK, 2002; pp. 95–120.
62. Fairclough, I.; Fairclough, N. *Political Discourse Analysis. A Method for Advanced Students*; Routledge: London, UK, 2012.
63. Mimura, N.; Pulwarty, R.; Duc, D.M.; Elshinnawy, I.; Redsteer, M.H.; Huang, H.-Q.; Nkem, J.N.; Rodriguez, R.A.S.; van Aalst, M.; Donohue, J.; *et al.* Adaptation planning and management. In *Intergovernmental Panel on Climate Change 5th Assessment Report. Working Group II Report*; Cambridge University Press: Cambridge, UK, 2014.
64. Bittner, M.-I.; Matthies, E.F.; Dalbokova, D.; Menne, B. Are European countries prepared for the next big heat-wave? *Eur. J. Public Health* **2013**, *24*, 615–619.
65. Adger, W.N.; Dessai, S.; Goulden, M.; Hulme, M.; Lorenzoni, I.; Nelson, D.R.; Naess, L.O.; Wolf, J.; Wreford, A. Are there social limits to adaptation to climate change? *Clim. Change* **2008**, *93*, 335–354.
66. Biesbroek, G.R.; Swart, R.J.; Carter, T.R.; Cowan, C.; Henrichs, T.; Mela, H.; Morecroft, M.D.; Rey, D. Europe adapts to climate change: Comparing national adaptation strategies. *Glob. Environ. Chang.* **2010**, *20*, 440–450.
67. Risher, J.F.; Todd, G.D.; Meyer, D.; Zunker, C.L. The elderly as a sensitive population in environmental exposures: Making the case. *Rev. Environ. Contam. Toxicol.* **2010**, *207*, 95–157.
68. Rechel, B.; Mladovsky, P.; Ingleby, D.; Mackenbach, J.P.; McKee, M. Migration and health in an increasingly diverse Europe. *Lancet* **2013**, *381*, 1235–1245.
69. Taylor, S. *What is Discourse Analysis?*; "What is?" Research methods series; Bloomsbury: London, UK, 2013.
70. Wooffitt, R. *Conversation Analysis and Discourse Analysis*; Sage: London, UK, 2006.
71. O'Brien, K.L.; Wolf, J. A values-based approach to vulnerability and adaptation to climate change. *Wiley Interdiscip. Rev. Clim. Chang.* **2010**, *1*, 232–242.
72. Van Dijk, T. Principles of critical discourse analysis. *Discourse Soc.* **1993**, *4*, 249–283.
73. Morgan, J.; Waskow, D. A new look at climate equity in the UNFCCC. *Clim. Policy* **2013**, *14*, 1–6.
74. Böhmelt, T. Civil society lobbying and countries' climate change policies: A matching approach. *Clim. Policy* **2013**, *13*, 698–717.
75. Balbus, J.M.; Bouma, M.; Kovats, S.; LeSueur, D.; Martens, W.C.; Patz, J. Human health. In *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*; Feenstra, J.F., Burton, I., Smith, J.B., Tol, R.S.J., Eds.; United Nations Environment Programme (UNEP): Nairobi, Kenya; Vrije Universiteit Amsterdam: Amsterdam, The Netherlands, 1998; Volume 2, pp. 10–31.

76. Said, E.W. *Orientalism*; 25 Annive.; Vintage Books: New York, NY, USA, 2003.
77. United Nations Framework Convention on Climate Change FOCUS: Mitigation—NAMAs, Nationally Appropriate Mitigation Actions. Available online: http://unfccc.int/focus/mitigation/items/7172.php (accessed on 21 August 2014).
78. Nguyen, M.T. *The Gift of Freedom: War, Debt, and Other Refugee Passages*; Duke University Press: Durham, NC, USA, 2012.
79. Lesnikowski, A.C.; Ford, J.D.; Berrang-Ford, L.; Paterson, J.A.; Barrera, M.; Heymann, S.J. Adapting to health impacts of climate change: A study of UNFCCC Annex I parties. *Environ. Res. Lett.* **2011**, *6*, doi:10.1088/1748-9326/6/4/044009.
80. Wilhelmi, O.V.; Hayden, M.H. Connecting people and place: A new framework for reducing urban vulnerability to extreme heat. *Environ. Res. Lett.* **2010**, *5*, doi:10.1088/1748-9326/5/1/014021.
81. Bolte, G. Environment-related inequalities. In *Environmental health inequalities in Europe. Assessment report*; World Health Organization, Ed.; WHO Regional Office for Europe: Copenhagen, Denmark, 2012; pp. 86–113.
82. Wardekker, J.A.; de Jong, A.; van Bree, L.; Turkenburg, W.C.; van der Sluijs, J.P. Health risks of climate change: An assessment of uncertainties and its implications for adaptation policies. *Environ. Heal.* **2012**, *11*, doi:10.1186/1476-069X-11-67.
83. Ebi, K.L.; Semenza, J.C. Community-based adaptation to the health impacts of climate change. *Am. J. Prev. Med.* **2008**, *35*, 501–507.
84. Falloon, P.; Betts, R. Climate impacts on European agriculture and water management in the context of adaptation and mitigation—The importance of an integrated approach. *Sci. Total Environ.* **2010**, *408*, 5667–5687.
85. Kunreuther, H.; Heal, G.; Allen, M.; Edenhofer, O.; Field, C.B.; Yohe, G. *Risk Management and Climate Change*; NBER Working Paper; Cambridge, MA, USA, 2012.
86. Cheng, J.J.; Berry, P. Health co-benefits and risks of public health adaptation strategies to climate change: A review of current literature. *Int. J. Public Health* **2013**, *58*, 305–311.
87. Remais, J.V.; Hess, J.J.; Ebi, K.L.; Markandya, A.; Balbus, J.M.; Wilkinson, P.; Haines, A.; Chalabi, Z. Estimating the health effects of greenhouse gas mitigation strategies: Addressing parametric, model, and valuation challenges. *Environ. Health Perspect.* **2014**, *122*, 447–455.
88. Horton, R.; Beaglehole, R.; Bonita, R.; Raeburn, J.; McKee, M.; Wall, S. From public to planetary health: A manifesto. *Lancet* **2014**, *383*, doi:10.1016/S0140-6736(14)60409-8.
89. Bassil, K.L.; Cole, D.C. Effectiveness of public health interventions in reducing morbidity and mortality during heat episodes: A structured review. *Int. J. Environ. Res. Public Health* **2010**, *7*, 991–1001.
90. Toloo, G.; Fitzgerald, G.; Aitken, P.; Verrall, K.; Tong, S. Evaluating the effectiveness of heat warning systems: Systematic review of epidemiological evidence. *Int. J. Public Health* **2013**, *58*, 667–681.
91. O'Brien, K. Global environmental change II: From adaptation to deliberate transformation. *Prog. Hum. Geogr.* **2011**, *36*, 667–676.

92. Townshend, T.; Fankhauser, S.; Aybar, R.; Collins, M.; Landesman, T.; Nachmany, M.; Pavese, C. How national legislation can help to solve climate change. *Nat. Clim. Chang.* **2013**, *3*, 430–432.

Article IV

Boeckmann, M. (2015a). **Exploring the health context: a qualitative study of local heat and climate change adaptation in Japan**. *Submitted.*

Abstract

Background: Extreme temperature events and global climatic changes may put human health at risk. Urban centers are particularly vulnerable to adverse effects of climate change. Japan is a densely populated and highly urbanized island frequently exposed to natural hazards. To protect human health under a changing climate, governments and practitioners across the globe are designing adaptation strategies. Are these strategies implemented at the local level? How do policymakers and researchers perceive heat and climate change adaptation measures? How are these strategies evaluated? In short: what is happening in Japan “on the ground”?

Methods: This exploratory qualitative study on the state of adaptation in urban Japan used semi-structured expert interviews and situational analysis to assess local realities and perceptions among eight government and research agencies employees in three prefectures. All interviews were transcribed and translated by native speakers and openly coded. The generated themes-based material was further analyzed through situational analysis social world and positional mapping.

Results: Results suggest that heat adaptation is widely implemented at the local level in Japan. These measures are not always conceptualized as climate change adaptation, however, but rather as general health interventions or environmental measures. Funding and prioritization of adaptation is a challenge especially since the Great East Japan Earthquake and tsunami of 2011, and risk perception and assignment of responsibility for action are contested. Equally difficult is evaluation of adaptation, which is perceived as scientifically challenging. Of high importance in the Japanese

adaptation case are community volunteers, whose roles vary from checking in on vulnerable persons to acting as citizen scientists.

Conclusions: Heat adaptation is a regular feature of environmental and health policy in urban Japanese centers, yet these measures are not always evaluated. Creative solutions from the Japanese context include a strong reliance on civil society and community volunteer actors. These local responses to global climate change could be further tested for their applicability to other contexts and settings.

Keywords: adaptation, heat, health policy, evaluation, qualitative research, situational analysis, exploratory study, climate change, global environmental change

Article V

Boeckmann, M. (2015b). **Reframing effectiveness: climate change adaptation, human health, and the role of climate justice in evaluation**. *Submitted.*

Abstract

Background

Climate change affects human health, and some regions and populations are more at risk from adverse health effects of climate induced extreme events than others. Climate change adaptation aims to reduce these risks through infrastructural, behavioral, and technological measures. Attributing changes in human health to possible effects of climate change adaptation is however difficult. This "evaluation problem" in adaptation could mean that adaptation implementation has to rely on the precautionary principle and novel concepts of effectiveness.

Discussion

To assess climate change adaptation and its justice implications, this paper proposes a theoretical framework that incorporates climate justice as a proxy for effectiveness into adaptation evaluation. Drawing from previously established domains linked to health, the paths between adaptation and the seven domains are the target of evaluation in this framework: as a proxy for direct effects of climate change adaptation on health outcomes which are difficult to measure, effects of adaptation on the seven domains can be assessed. The underlying principle of the proposed framework is an adaptation strategy's potential for climate justice that serves as proxy indicator for effectiveness in adaptation evaluation. Seven domains, including social, economic, infrastructure, institutional, community, environmental and cultural determinants of health, are all interconnected and potentially influenced by climatic changes. As these areas also contribute to health inequities, assessing whether adaptation reduces these inequities is linked to the social justice imperative of public health.

Summary

In this framework, adaptation is positioned between climate change and the seven domains, and acts as a mediator of climate change effects on the determinants of health. At the same time, societal developments within each of these fields influence adaptation scope, design and effects. Each domain can be operationalized by specific indicators tailored to the concrete situation or data availability. As such, the framework could be a useful template to both researchers and policymakers. The framework is not supposed to replace empirical analysis, but rather to inform it. Such a re-thinking of effectiveness might contribute to climate justice and health promotion in the current absence of gold standard evaluation of health-related adaptation.

Keywords: climate change, effectiveness, social inequalities, environmental health, ethics, adaptation, framework, public health

10 Appendix

A: Interview guideline in English and Japanese

B: Code list

Additionally on CD-ROM:

List of codings

Expert interviews

Preliminary remarks:

The aim of this research project is to generate information on the status of adaptation to heat in Japan. I am also interested in how the effects of heat adaptation on human health can be measured.

この研究プロジェクトの目的は、日本における気候変動（温暖化）への適応策の状況に関する情報を得ることです。私はまた、適応策により人の健康がどの程度改善するか、その効果を測定する方法に興味を持っています。

In this interview, I would like to talk about what climate change adaptation projects the prefecture is implementing, what the process is like, and if any evaluation of the projects is planned. Specific information on your heat stroke prevention plans is especially interesting to me.

このインタビューでは、どのような気候変動適応プロジェクトを実施し、どのようなプロセスを経て行われているか、また、そのプロジェクトの効果についての評価が実施されているか（計画されているか）についてお話をお聞きしたいと考えています。特に、熱中症を予防するための計画に関する具体的な情報に関心があります。

This interview with you plays an important part in my research.

このインタビューは、私の研究の重要な部分を占めます。

As an adaptation professional, you decide which adaptation measures will be implemented. I am interested in learning from you, how you choose what measures to conduct and how effective you think these measures can be in reducing health risks.

専門的な見地から、どのような適応策を実施するべきかを決めていることと思います。どのように実施すべき適応策を選択したのか、選択した適応策が気候変動に伴う健康リスクを減らすのに、どの程度効果があるのか、興味があり、詳細について知りたく思います。

Your data and all information provided will remain confidential. That means I will anonymize quotes for publication and not use your name in my dissertation. You are voluntarily participating and may stop the interview at any point. If you feel uncomfortable with a question, you don’t have to answer it.

インタビューで得られるデータと提供されるすべての情報の機密は守られ、ご本人の許可なしに第三者に開示することはありません。このインタビューはあなたの自発的参加に基づくもので、任意の時点でインタビューを止めることができます。あなたの情報は匿名化され、個別の発言を引用する場合には、匿名で使用されます。あなたが答えたくない質問に対しては、答える必要はありません。

May I audio-record the interview?

オーディオレコードのインタビューはいいですか。

Questions part 1:

気候変動に対する適応策

1.1 Please tell me about the climate change adaptation projects in …

1.1 気候変動適応するための対策プロジェクト（全般）について教えてください。

1.2 Please tell me about projects with a health component.

1.2 対策のうち、健康に関連する プロジェクトについて教えてください。

1.3 Please tell me about the heat stroke prevention projects in …

1.3 熱中症を予防するための対策プロジェクトについて教えてください。

1.4 Why were these measures chosen in particular? Can you tell me a little about the process?

1.4 これらの対策を選ばれた理由はなんでしょうか？対策を選ぶ具体的なプロセスについて教えてください。

1.5 Can you tell me something about challenges and difficulties with the implementation process?

1.5 この対策を実施する過程で困難や課題はありましたか？もしあれば、その内容につ いて教えてください。

1.6 Please also tell me about any projects in … on urban planning, measures to increase parks in the city etc.

1.6 また、気候変動の適応策として、都市計画に関連する適応策や、公園を増やす等の対策があれば、それらについて教えてください。

1.7 Do you (or your section) collaborate with other sections for planning/implementing adaptation measures?

1.7 他に県内の適応計画実施に取り組んでいる担当者や部署は存在しますか？また、他部署と連携して取り組むことはありますか？

1.8 Can you tell me details about this cooperation?

1.8 この協力・連携の詳細について教えていただけないでしょうか？

Questions part 2:

Measuring and evaluating

Let's talk about how to measure heat stroke prevention and climate change adaptation:

熱中症予防の効果と**気候変動適応**をどのように評価するか、その方法についてお尋ねします。

2.1 Has there been an evaluation of the measure?
2.1 熱中症予防策の効果については、評価されていますか？

2.2 Can you tell me more about this evaluation?

2.2 この評価方法について具体的に教えてください。

2.3 Which indicators were used in the evaluation?

2.3 評価のためには、どのような指標を用いましたか？

2.4 Can you tell me more about these indicators?

2.4 その指標について具体的に教えてください。

2.5 Were there any problems with the evaluation? For example, information that was needed but was not available?

2.5 評価することに問題がありましたか？例えば、必要な情報が得られなかったということはありますか？

If there hasn't been an evaluation yet:

まだ評価が行われていない場合：

2.6 Please tell me more about the future of your project: what are the next steps?

2.6 将来、**実施を予定している、あるいは計画している対応策の評価についてさらに教えてください：次のステップとして、何を予定していますか？**

2.7 Is there anything else you'd like to say on heat, adaptation or evaluation?

2.7 気候変動、その適応策、適応策の評価について何か付け加える情報があれば、教えてください。

Thank you very much for the discussion and your time. If you'd like, I can keep you updated on the state of my research project.

インタビューのために貴重なお時間をいただきまして誠にありがとうございました。ご希望があれば、私の研究プロジェクトの進捗状況について、お知らせいたします。

Codesystem [611]

challenges to adaptation [53]

describes any challenge mentioned that is associated with why adaptation cannot or is not implemented

adaptation under a different name [3]

describes adaptation being implemented that is not called adaptation

mitigation or adaptation? [8]

describes where the both terms are conceptually not cleary distinguished from each other, where mitigation efforts are described as adaptation, for instance

prioritisation after Fukushima [4]

allocation of funds and priorities within governments in Japan after the nuclear disaster

risk perception [18]

describes statements of risks perceived

climate risks [21]

describes risk factors to health that arise from climatic changes

Health effects of heat [17]

describes any adverse health effects from extreme heat

risk factor for adverse health effects of heat [0]

risk factor: population density [6]

describes the risk factor population density in heat

risk factor: no air conditioning [4]

describes where air conditioning is not available or reduced as a risk factor

risk factor: built environment [1]

describes the built environment

risk factor: air pollution [1]

describes air pollution as climate risk for health

communication [69]

describes channels, efforts and institutions regarding communication between people or actors/actants on issues of climate change, adaptation and health

research policy interaction [5]

preliminary code, describes specific relationship between policy and research institute

creative solutions to adaptation [28]

describes creative measures undertaken in light of adaptation challenges

we offer an orientation to communities [1]

civil society involvement [23]

describes actions that involve civil society, such as volunteers or NGOs

evaluation [34]
describes themes related to evaluation of adaptation: here, heat stroke specific

challenges to evaluation [17]
describes challenges, difficulties and issues that arise when discussing how to measure adaptation effects

proof/effects [32]
preliminary code on anything related to effects, proof of climate change or adaptation

state of adaptation [35]
refers to the state adaptation is in, from planning to implemention, excluding evaluation

scale [32]
describes the scale of adaptation implementation including responsibilities assigned, of adaptation material reach

adaptation research methods [16]
describes specific methodology for research on adaptation and evaluation of adaptation

type of adaptation [0]
type of adaptation: targeting high risk groups in person [16]
describes an adaptation where older persons are targeted for specific actions

type of adaptation: structural [16]
describes structural intervention projects such as greening, providing access to cool spaces, wind tunnels

type of adaptation: legislation [3]
describes any legislative measures intended as climate adaptation

type of adaptation: information and behavior [37]
describes adaptation measures targeting behavioral change through information and awareness raising

vulnerable population [22]
describes the persons deemed at risk from heat

responsibility [87]
describes who is responsible for an adaptation or evaluation action

precautionary principle [2]
describes preventing harm as reasoning for adaptation

Sets [0]

Erklärung

Hiermit erkläre ich, Melanie Böckmann, dass ich die vorliegende Arbeit *„Exploring the health context: A multimethod approach to climate change adaptation evaluation"* ohne unerlaubte fremde Hilfe angefertigt habe. Ich habe keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt, und die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht.

Weiterhin hin bestätige ich, dass ich mich keinem weiteren Promotionsverfahren unterzogen oder ein solches beantragt habe.

Ort, Datum Melanie Böckmann