UNDERSTANDING SOCIAL-ECOLOGICAL SYSTEMS UNDER CLIMATE CHANGE – EXPLORING THE ECOSYSTEM SERVICE CONCEPT TOWARDS AN INTEGRATED VULNERABILITY ASSESSMENT

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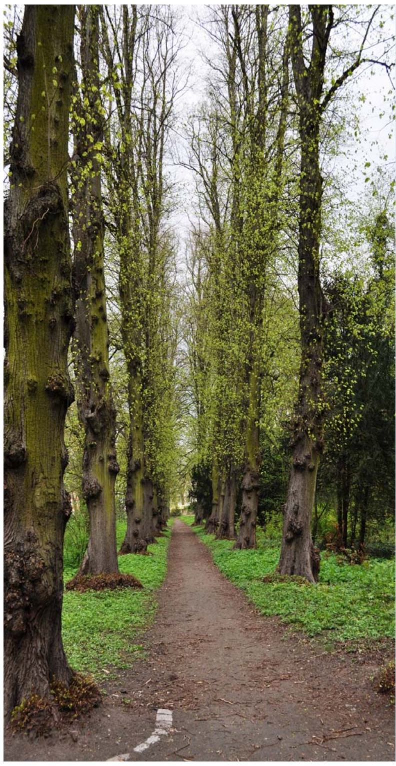

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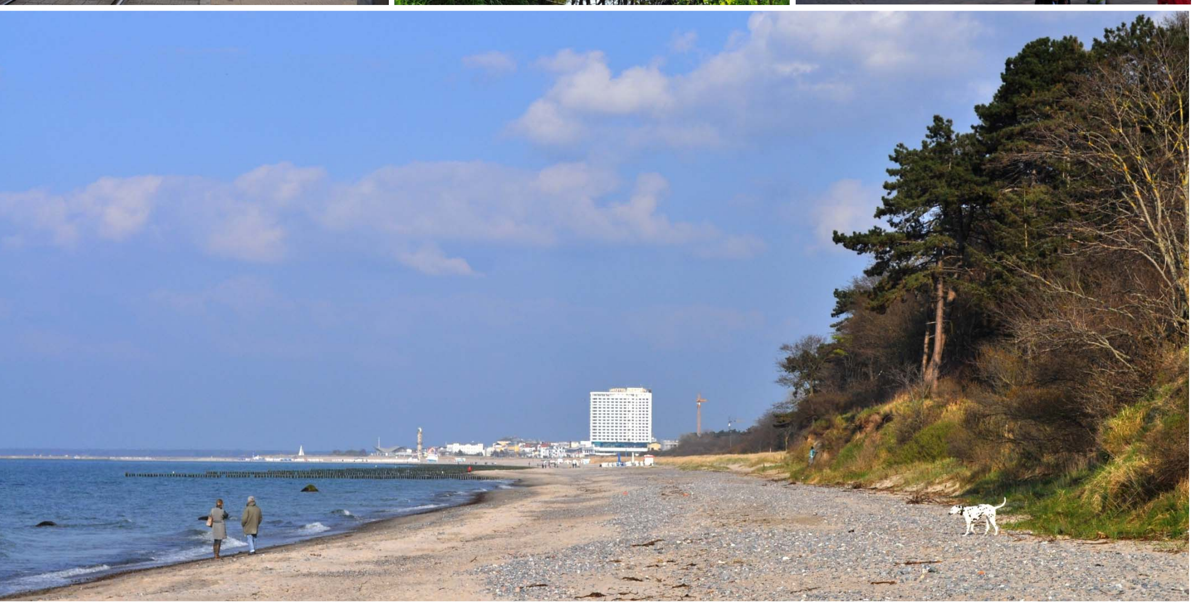

DISSERTATION - HAFENCITY UNIVERSITÄT HAMBURG

UNDERSTANDING SOCIAL-ECOLOGICAL SYSTEMS UNDER CLIMATE CHANGE– EXPLORING THE ECOSYSTEM SERVICE CONCEPT TOWARDS AN INTEGRATED VULNERABILITY ASSESSMENT

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EURA Conference 2012, Wien, Österreich, 20.-22.09.2012.

c) Hagemeier-Klose, M.; Beichler, S.: “*The Dynamic Knowledge Loop – Inter- and Transdisciplinary Cooperation and Adaptation of Climate Change Knowledge*”.
European Climate Change Adaptation Conference, Hamburg, 18.-20.03.2013.

d) Beichler, S.; Deppisch, S.: “*Why do we like our city? Exploring the ecosystem service cascade through the lens of social-ecological adaptation*”.
IALE-EU Congress - Changing European Landscapes, Landscape ecology local to global Symposium "Ecosystem Services: building informed policies to orient landscape dynamics" Manchester 09.-12.09.2013

e) Beichler, S.; Deppisch, S.: „*Was leistet Ihre Stadt heute, und morgen? Partizipative Erhebung von kulturellen Ökosystemdienstleistungen in Rostock*“.
IALE-D Tagung, Dresden 10.-12.10.2013

f) Beichler, S.: “*Exploring the use of participatory mapping in indicator development Cultural ecosystem services in the urban region of Rostock (Germany)*”.
Postervortrag Ecosystem Service Partnership Meeting, Kiel 6.-8. Mai 2013.

g) Beichler, S.: „*The social-ecological vulnerability of an urban region*”.
Conference Urban Regions under Change: towards social-ecological resilience, Hamburg 27.05.2014

Lesehinweise zur Zitation in der vorliegenden Arbeit:
Teilweise waren die Inhalte der Tagungsbeiträge Arbeiten die in den jeweiligen Journal Artikeln resultierten. In diesem Falle wird in der Dissertation immer auf die offizielle schriftliche Veröffentlichung d.h. den Artikel (siehe Seite 1) verwiesen.
Im Kapitel „Introduction“ wird speziell in Fußnoten auf die hier aufgeführten Vorabveröffentlichungen verwiesen um einen Überblick über deren Verwendung zu geben.

ABBREVIATIONS

- aest aesthetics and inspiration
- CES cultural ecosystem services
- cult cultural heritage and identity
- DPSIR driver-pressure-state-impact-response
- DTH distance to home
- edu knowledge and education
- nat natural heritage and intrinsic value of biodiversity
- recr recreation
- SES social-ecological system
- spirit spiritual and religious

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1 ABSTRACT

Urban and regional planning is confronted with the challenge to develop measures for climate change adaptation. In this context, on the one hand vulnerability assessments are increasingly requested by decision makers in order to prioritize actions. On the other hand, it is argued in literature that ecosystem based adaptation could assist in finding long-term adaptation strategies, whereby ecosystem services could serve as a common language. This signalizes the need to combine the vulnerability and the ecosystem service concept, which so far have been developed in parallel. Against this background, the thesis presents a framework that integrates the concepts in order to enhance the understanding of social-ecological systems under climate change.

Inter- and transdisciplinary research approaches were undertaken to unravel the complex characteristics of social-ecological systems and issues related to climate change. First, studies from various disciplines related to vulnerability, ecosystem services, and resilience were investigated. The results clearly demonstrate conceptual overlaps and methodological limitations particularly regarding the balanced focus on the social and the ecological system. Moreover, elements that ought to be included in an integrated approach were revealed. Thereby, the underlying objective was to develop a method that allows a comprehensive spatial characterization of the urban region as a basis for an integrated vulnerability assessment. For the development of a framework, the Driver-Pressure-State-Impact-Response approach served as a pragmatic tool to structure the vulnerability elements and associated analytical steps. The social-ecological vulnerability loop proposed here, combines vulnerability and ecosystem service supply and demand, whereby a consideration of the social and the ecological system as well as their interactions was achieved.

To apply the proposed framework, methods directed towards the understanding of adaptive capacity and the linkages between ecosystem service supply and demand were developed and applied in the urban region of Rostock (Germany). A comprehensive dataset was obtained through the participatory mapping of the cultural ecosystem services aesthetics / inspiration, spiritual / religious, recreation, knowledge / education, cultural heritage / identity, and natural heritage / intrinsic value of biodiversity, as well as the participants' perceived vulnerability to extreme precipitation, heat wave, and drought. Besides the mapping, the participants evaluated the importance of the individual cultural ecosystem services for their wellbeing as well as their satisfaction with supply in the urban region. Adaptive capacity was approached by a combination of inter- and transdisciplinary methods exploring knowledge aspects (exchange, generation) in science-science and science-practice cooperations. To investigate supply-demand relationships, the categorical link between social factors and the importance of the cultural ecosystem services for wellbeing, as well as the spatial link between population and cultural ecosystem service were analyzed. Remarkably, no differences according to social factors were found considering the relation to the importance for wellbeing as well as the spatial link. Furthermore, the differences between the services highlighted the high importance of both, recreation and natural heritage / intrinsic value of biodiversity. Through the established critical distances between supply and demand ranging from 2-7 km for the individual cultural ecosystem services, the innovative integrated supply-demand map was generated. This allowed for the first time a clear spatially explicit visualization of the differences between the city, the hinterland, and coastal areas as well as the potential vulnerability to climate change in the urban region. In this regard, the total area, the number, and the diversity of cultural ecosystem services were identified as key parameters. Through the enhanced understanding of the supply-demand relationships, it was possible to characterize the elements of the social-ecological system as well as their interactions. Therewith, responses in terms of adaptation measures can be linked to consequences for the whole system. The proposed comprehensive social-ecological approach can assist planning in the formulation of targets, the identification of suitable areas, and the reflection of potential shortcomings. Finally, it was highlighted that a development of adaptation measures in combination with cultural ecosystem services can create win-win opportunities and therewith facilitate the implementation of long-term strategies.

Zusammenfassung

Die Anpassung an den Klimawandel stellt eine große Herausforderung für die Stadt- und Regionalplanung dar. In diesem Kontext wird einerseits von Praktikern verstärkt der Bedarf an Untersuchungen zu Vulnerabilität geäußert. Anderseits wird in der Literatur darauf hingewiesen, dass ein ökosystembasiertes Management zur Entwicklung von langfristigen Anpassungsoptionen beitragen kann, wobei Ökosystemleistungen als Grundlage für die Verständigung zwischen Praktikern dienen könnten. Dies unterstreicht die Notwendigkeit, die Konzepte von Vulnerabilität und Ökosystemleistungen miteinander zu kombinieren, denn bisher wurden diese Konzepte unabhängig voneinander entwickelt. Vor diesem Hintergrund präsentiert die vorliegende Arbeit ein Rahmenkonzept, das beide Konzepte integriert, um somit zu einem besseren Verständnis von sozial-ökologischen Systemen im Klimawandel beizutragen.

Im Forschungsprozess wurden inter- und transdisziplinäre Ansätze angewendet, um den komplexen Eigenschaften von sozial-ökologischen Systemen und der Problemstellung des Klimawandels auf den Grund zu gehen. Dabei wurden zunächst Studien mit Bezug zu Vulnerabilität, Ökosystemleistungen und Resilienz aus unterschiedlichen wissenschaftlichen Disziplinen untersucht. Die Ergebnisse zeigen klar konzeptionelle Überschneidungen und methodische Einschränkungen insbesondere hinsichtlich der Berücksichtigung des sozialen und des ökologischen Systems auf. Desweiteren wurden Elemente, die in einem integrierten Ansatz berücksichtigt werden sollen, identifiziert. Das Hauptziel der vorliegenden Arbeit war dabei eine Methode zu entwickeln, die eine umfassende räumliche Charakterisierung von sozial-ökologischen Systemen ermöglicht, um daraus eine integrierte Vulnerabilitätsanalyse abzuleiten. Als Ausgangspunkt für die Entwicklung des Rahmenkonzeptes wurde der Driver-Pressures-State-Impact-Response (DPSIR) Ansatz genutzt, da dieser es ermöglicht, die Vulnerabilitätselemente und assoziierten Analysen zu strukturieren. Die hier vorgestellte sozial-ökologische Vulnerabilitäts-Schleife (social-ecological vulnerability loop) verbindet erstmals Vulnerabilität mit dem Angebot von und der Nachfrage nach Ökosystemleistungen (ecosystem service supply and demand). Dadurch konnte erreicht werden, dass sowohl das soziale als auch das ökologische System und insbesondere deren Interaktionen in die Vulnerabilitätsanalyse mit einbezogen wurden.

Für die Umsetzung des Rahmenkonzeptes wurden innovative Methoden entwickelt, um in der Stadtregion Rostock (Deutschland) die Anpassungskapazität (adaptive capacity) hinsichtlich des Klimawandels und die Verknüpfungen zwischen dem Angebot von und der Nachfrage nach Ökosystemleistungen konkret darzustellen. Hierzu wurde eine partizipative Erhebung durchgeführt hinsichtlich der kulturellen Ökosystemleistungen Ästhetik / Inspiration, spirituell / religiös, Erholung, Wissen / Bildung, kulturelles Erbe / Identität und Naturerbe / intrinsischer Wert von Biodiversität sowie der wahrgenommen Vulnerabilität der Teilnehmer in Bezug auf Starkregen, Hitzewelle und Dürre. Neben der Kartierung haben die Teilnehmer die Bedeutung der einzelnen kulturellen Ökosystemleistungen für ihr Wohlbefinden sowie ihre Zufriedenheit mit der Bereitstellung bewertet. Die Anpassungskapazität wurde mittels einer Kombination aus inter- und transdiziplinären Methoden untersucht, wobei Wissensaspekte (Austausch, Generierung) in der Kooperation zwischen Wissenschaftlern sowie zwischen Wissenschaft und Praxis betrachtet wurden. Um die Verbindung von Ökosystemleistungsangebot und -nachfrage zu bestimmen, wurde der Zusammenhang zwischen sozialen Faktoren und der Bedeutung von kulturellen Ökosystemleistungen für das Wohlbefinden sowie die räumliche Verknüpfung zwischen kulturellen Ökosystemleistungen und der Bevölkerung untersucht. Bemerkenswerterweise wurde kein signifikanter Einfluss der sozialen Faktoren auf die Bedeutung der Ökosystemleistungen für das Wohlbefinden sowie auch hinsichtlich der räumlichen Verteilung gefunden. Außerdem konnte gezeigt werden, dass in der Stadtregion Rostock Erholung einerseits und Naturerbe / intrinsischer Wert von Biodiversität andererseits von gleich hoher Bedeutung für das Wohlbefinden sind. Auf Basis der ermittelten kritischen Distanzen zwischen Angebot und Nachfrage für die einzelnen kulturellen Ökosystemleistungen im Bereich von 2-7 km wurde erstmals eine integrierte Angebots-Nachfrage-Karte für die Stadtregion erstellt. Dies ermöglichte eine räumlich explizite Darstellung der Unterschiede zwischen Stadt, Umland und Küstenbereich und der potentiellen Klimawandel-Vulnerabilität. Dabei wurden als Hauptmerkmale bei der Analyse von Stadtregionen die Gesamtfläche, die Anzahl und die Diversität der kulturellen Ökosystemleistungen identifiziert. Das verbesserte Verständnis des Zusammenhangs zwischen Angebot und Nachfrage ermöglichte es, die Elemente des sozial-ökologischen Systems und deren Interaktionen zu charakterisieren. Auf dieser Grundlage können die Auswirkungen von Anpassungsmaßnahmen an den Klimawandel auf das gesamte sozial-ökologische System dargestellt werden. Der vorgestellte umfassende sozial-ökologische Ansatz kann die Planung dabei unterstützen, Ziele zu formulieren, geeignete Flächen zu identifizieren und mögliche Konsequenzen von Maßnahmen zu reflektieren. Damit konnte erstmals aufgezeigt werden, dass Klimawandelanpassung in Verbindung mit kulturellen Ökosystemleistungen Win-Win-Situationen ermöglicht, die die Umsetzung von langfristigen Strategien erheblich fördern.

2 INTRODUCTION

This thesis is indented to contribute to the understanding of dynamics of social-ecological systems under climate change. Already since the IPCC report in 2007, it became clear that climate change adaptation is needed alongside mitigation strategies (IPCC, 2007). Adaptation to climate change is considered one of the largest challenges facing regional and urban development, as innovative local planning decisions need to be taken under uncertainty (Mooney et al., 2009). To be able to handle this challenge, it is required to gain knowledge about the characteristics of climate change impacts, as well as to evaluate possible responses and to prioritize investments and adaptation measures (Adger, 2006; Hinkel and Klein, 2009). In this context, the term vulnerability is increasingly used in many disciplines with definitions differing considerably (De Lange et al., 2010). However, most studies, in accordance with the IPCC definition (IPCC, 2007), agree on the main vulnerability-components being exposure, sensitivity, and adaptive capacity, and their dynamic interactions (Adger, 2006; De Lange et al., 2010). The classification and the detailed meaning of the elements are however ongoing subjects of discussion (Gallopín, 2006; Hinkel, 2011).

In central Europe and particularly Germany, the predicted effects of climate change in terms of increased urban heat island effects, changes in the precipitation regime, and the increase of extreme events are comparatively moderate (IPCC, 2012), but will have considerable effects on the quality of life especially in cities (EEA, 2009). Hence, climate change adaptation is needed. Yet, as the risk of fatalities is currently low, it bears the opportunity to develop long-term adaptation strategies, which could contribute to achieving a more sustainable development in general. Important approaches in this context are ecosystem based adaptation and management. Ecosystem based adaptation considers ecosystem degradation and the associated decrease of ecosystem services to manage the vulnerability of the society to climate change (Vignola et al., 2009). Ecosystem based management takes into account the role of ecological structures and processes as well as the interconnectedness of the social and the ecological system. Here, ecosystem services could serve as a common language for comparing management options (Granek et al., 2010). That context signalizes the need for methods that allow for an integrated analysis of the social-ecological system in terms of ecosystem services and vulnerability.

The concept of social-ecological systems (Ostrom, 2009) and their inherent interactions has been adopted by many research disciplines. Vulnerability research shows a trend towards system oriented approaches that consider the vulnerability of social-ecological systems holistically (Adger, 2006) including the analysis of multiple variables in relation to various driving forces (De Chazal et al., 2008; Luers, 2005). However, although many theoretical vulnerability frameworks exist (e.g. Metzger et al., 2006; Turner et al., 2003a), they are seldom put into practice (Hinkel and Klein, 2009) or give little reference to practical applications in decision-making (Luers, 2005).

The ecosystem service concept is an application oriented framework to analyze social-ecological systems (Burkhard et al., 2010b; Müller et al., 2010b). There are diverse ecosystem service assessment approaches (Hermann et al., 2011). However, in order to be relevant for decision-making, studies need to be more stakeholder-oriented and transparent (Cowling et al., 2008; Daily et al., 2009), and should allow for interdisciplinary integration, which is useful for target setting, discussion, and reflection (Termorshuizen and Opdam, 2009). As such, comparing vulnerability and ecosystem services approaches, it can be stated that both are indicator based and take a social-ecological approach. On the one hand, vulnerability studies often focus on the identification of areas with urgent need for action or with the highest impact on people, thus focus on the social system, and are hard to be translated into practical measures. On the other hand, ecosystem service studies focus on the identification of areas with ecosystem service supply, which could be translated into practical measures. However, ecosystem service studies are often thought to be only relevant for the environmental sector, as they focus more on the ecological system and are less stakeholder oriented, especially in terms of target setting. This suggests that through the cross-fertilization of disciplines, a combination of both concepts could be of high value, as there is a need for more research on the description of complex social-ecological systems as a basis of vulnerability analysis (Luers, 2005).

Against this background, it becomes clear that to understand the effects of climate change and to find effective adaptation strategies, input from various scientific disciplines is required. The integration between and across disciplines is described by a range of theoretical approaches referring to multidisciplinarity, interdisciplinarity, or transdisciplinarity (Mobjörk, 2010; Stock and Burton, 2011) that are however related to a variety of meanings (Stock and Burton, 2011). In this thesis, interdisciplinarity refers to approaches, where knowledge of different disciplines is accumulated and integrated to bridge disciplinary boundaries, e.g. between social and natural science (Stock and Burton, 2011). In this context, this thesis deals on the one hand with the state of the art in literature related to different disciplines. As multiple concepts such as multifunctionality, sustainability, ecosystem services, vulnerability, and resilience exist in parallel, there is a need for integrative approaches (Bruckmeier, 2012; Burkhard et al., 2010b; O'Farrell and Anderson, 2010; Turner, 2010). On the other hand, the interdisciplinary discussions within the research project plan B:altic related to e.g. issues of spatial planning, governance, and knowledge will be reflected. Therewith, the often requested need for interdisciplinary exchange of knowledge in the context of climate change adaptation (Sanchez-Rodriguez, 2009) will be addressed. Moreover, in this thesis, transdisciplinarity refers to approaches that explicitly include cooperation between researchers and practitioners from outside academia (Mobjörk, 2010). Multiple studies underlined the need to include stakeholders into the research process. Thus, the importance of local knowledge in studies concerning vulnerability, ecosystem services, and social-ecological systems is emphasized (Bruckmeier, 2012; Hutton et al., 2011; O'Farrell and Anderson, 2010; Smit and Wandel, 2006). These issues are acknowledged by applying a participatory approach in the spatial analysis of this thesis.

Urban regions represent interesting "laboratories" to understand patterns and processes related to human modifications in the context of global change (Grimm et al., 2008). This is due to the high population density and the high degree of imperviousness that increase the potential vulnerability. Moreover, urban regions are interesting laboratories for the application of the ecosystem service concept linking science with planning (Ahern, 2012). Due to the interaction between the city and its hinterland, the concept of ecosystem service supply and demand could give insights in understanding spatial relationships. In this context, the use of a social-ecological system approach is an excellent supplement to explore sustainability science beyond interdisciplinary approaches (Angelstam et al., 2013). Although, vulnerability studies consider the social and the ecological system, the results often give solely information on people or places that might be impacted, but they rarely indicate where adaptation could take place. In contrast, ecosystem service studies point at areas with potential for adaptation, but the direct link to the people often remains unclear. As such, it is important to consider both, the supply and demand of ecosystem services as done in more and more studies in recent years (Baró et al., 2015; Nedkov and Burkhard, 2012; Stürck et al., 2014; Wolff et al., 2015). Especially in the context of climate change, research on the interactions between the supply and the demand, and the related indirect effects of climate change is necessary.

Given this multitude of approaches that exists in parallel, the main question is, how the social-ecological system of an urban region and its dynamics can be described combining existing approaches. To find answers to this question, the thesis aims at finding a way to operationalize the vulnerability concept and the ecosystem service concept in an integrated manner.

Against this background, the thesis has two main objectives:

- Investigating social-ecological system approaches regarding climate change adaptation in the inter- and transdisciplinary context
- Developing a method for the spatial characterization of the urban region as a basis for vulnerability assessment including the distribution of ecosystem services and the link between supply and demand

The theoretical background is elucidated in detail in the individual chapters concerning vulnerability, ecosystem services, the interdisciplinary work, and the developed framework.

The thesis explores the use of the ecosystem service concept with the ambition to develop an integrated approach for the assessment of vulnerability. The practical background of the study is adaptation to climate change in urban regions that are understood as social-ecological systems. Given the complexity of the topic, which is influenced by several scientific disciplines, concepts that exist in parallel, the need for methodological development as well as inter- and transdisciplinary research approaches, the thesis is divided into three parts (Figure 1): the theoretical examination and integration of the different concepts (blue), method development and the application of the framework (yellow and orange), and the integrating discussion (green).

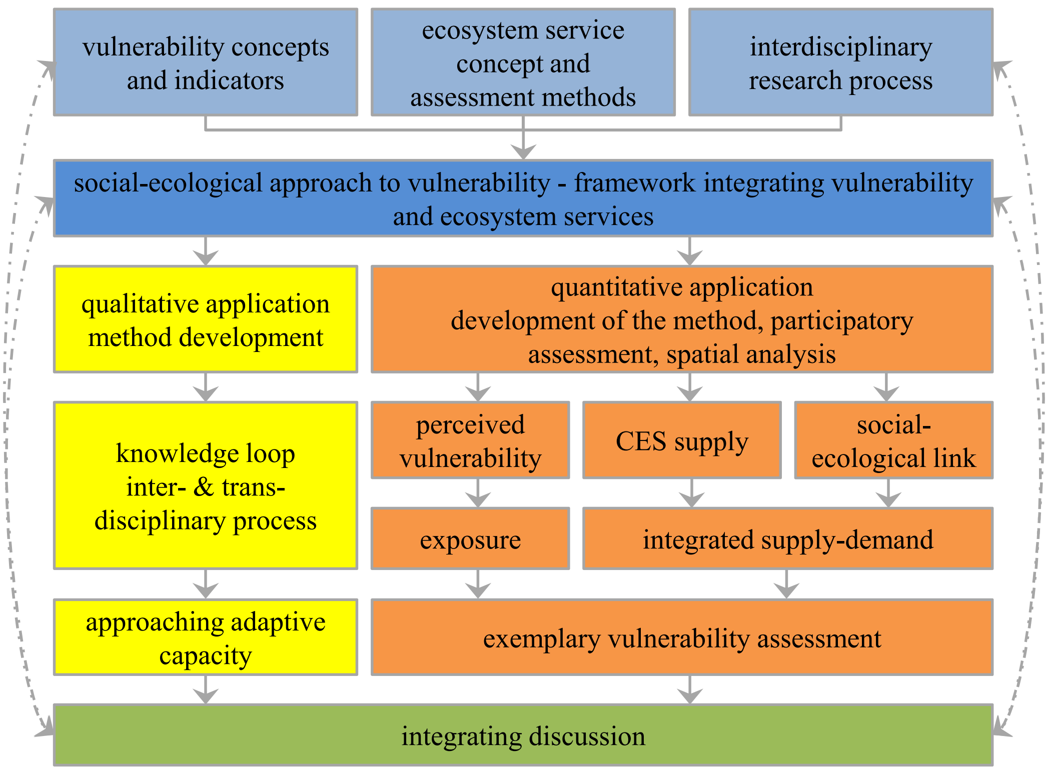

Figure 1: Description of the research process: the theoretical examination of the different research approaches resulting in the integrated framework (blue), the qualitative application (yellow), and the quantitative application case study on cultural ecosystem services (CES) (orange), as well as the integrating discussion (green)

The **first part** of the thesis is of conceptual and theoretical nature (cf. Figure 1, blue) taking an interdisciplinary perspective in the reflection of literature. First, a short overview on **vulnerability approaches** is given. The elements of vulnerability and associated indicators are evaluated against the background of a social-ecological system approach (Chapter 3)[1]. Furthermore, the **ecosystem service concept** is introduced focusing on the urban context. An overview on assessment approaches and the applications of the ecosystem service concept in practice is presented, whereby the discussion emphasizes the handling of urban structures (Chapter 4)[2]. Morover, the process of **interdisciplinary integration** within the research project plan B:altic is presented (Chapter 5) [3]. Herein, the use of resilience as a bridging concept is discussed reflecting the interdisciplinary process and the implications derived for the thesis

[1] Parts based on the presentation a) Beichler et al. (2012) cf. page 2
[2] Parts based on the article manuscript Beichler et al. (2017) cf. page 1
[3] Parts based on the article Beichler et al. (2014) cf. page 1

regarding vulnerability elements and the social-ecological approach. Considering the first three elements of the thesis (Figure 1, light blue), the literature on the different concepts was compiled, summarized, and reflected in an iterative research process. As such, the chapters on vulnerability, ecosystem services, and the interdisciplinary process are closely interwoven, as one finding was reflected back to the other conceptual approaches.

The first part of this thesis ends with the resulting integrated **theoretical framework** (Chapter 6)[1]. Herein, the concepts are combined under the Driver-Pressure-State-Impact-Response framework (DPSIR).

The goals of the theoretical part are related to the following focal research questions:

- *Which theoretical frameworks can be used to describe the vulnerability of social-ecological systems?*
- *How can the different concepts be integrated to describe the vulnerability of the social-ecological system and its dynamics*?

The **second part** of this thesis (Figure 1, yellow and orange) refers to the application of the framework. First, the **urban region of Rostock** is introduced, summarizing the basic information on the **case study** region as well as the broad interdisciplinary knowledge base derived through the transdisciplinary scenario process. Moreover, the empirical data and **developed methods** are described that provide the basis for the following application of the framework (Chapter 7). In the **qualitative application** (Figure 1, yellow), the theoretical framework is reflected in the inter- and transdisciplinary context (Chapter 8). The aspects of knowledge are emphasized in order to approach adaptive capacity. In the **quantitative application** (Figure 1, orange), the results of the case study focusing on **cultural ecosystem services** (CES) in the urban region of Rostock are presented (Chapter 9)[2]. Here, the spatial characterization of the urban region by means of ecosystem service supply and the relation to land use classes, the exploration of the link between supply and demand considering social factors, and the implications regarding vulnerability in the urban region are presented.

[1] Parts based on the presentation b) Beichler et al (2012) cf. page 2
[2] Parts based on the article Beichler (2015) cf. page 1

The second part addresses specifically the questions:

- *How can the adaptive capacity of a social-ecological system be characterized and evaluated in the face of climate change*?
- *Which methods can be used to characterize the social-ecological system quantitatively as a basis for vulnerability assessment?*
- *Which interrelations between the social and the ecological system can be found and what are implications regarding climate change adaptation?*

All findings are brought together in the **integrating discussion** (Figure 1, green). Here, the results are reflected in the context of the overall thesis presenting limitations of the study, future research needs, and implications for adaptation (Chapter 10). Finally, the **conclusion** answers the research questions posed.

3 VULNERABILITY

Vulnerability research has developed in parallel within the social and biophysical science. Traditionally, vulnerability studies focused either on the social sector, meaning the vulnerability of people, or on the spatial assessment of natural hazards related to different sectors, such as agriculture or water (Adger, 2006; De Chazal et al., 2008; Luers, 2005). Currently, the different scientific disciplines in the context of climate change research are merging, towards system oriented approaches, which consider the vulnerability of social-ecological systems in a holistic manner (Adger, 2006; Folke, 2006). Numerous vulnerability approaches (e.g. Brooks et al., 2005; Brown et al., 2014; Füssel, 2010; Lissner et al., 2012; Metzger and Schröter, 2006; Metzger et al., 2006, 2005; Reyer et al., 2012; Schauser et al., 2010) are based upon the IPCC (2007, 2001) definition referring to vulnerability as a function of exposure, sensitivity, and adaptive capacity (Table 2), which was also the starting point of this thesis. In contrast, the disaster risk approach (Table 1) refers to hazard, exposure, vulnerability, and resilience as being key elements (UNISDR, 2011). The definition of Adger (2006) in turn uses the terms susceptibility and capacity to adapt, whereas expanded vulnerability takes resilience, exposure, and sensitivity into consideration (Table 1). A detailed description of the different fields of vulnerability research (e.g. climate and global environmental change, development and livelihood, human ecology), schools of thoughts, and a detailed examination of approaches (e.g. risk-hazard, pressure-and-release, expanded

Table 1: Vulnerability definitions

Disaster risk (UNISDR 2011, p.x)	"[…]**disaster risk** is considered to be a function of hazard, exposure and vulnerability. **Exposure**: "location of people or economic assets in hazard-prone areas." **Vulnerability**: "susceptibility to suffer damage and loss" **Resilience**: "the capacity of systems to absorb or buffer losses, and recover.
Vulnerability (Adger 2006, p.268)	"the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt"
Expanded vulnerability (Turner 2003, p. 8074 & 8075)	"**Vulnerability** is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard […]" **Resilience**: "The system's capacities to cope or respond" **"Exposure** beyond the presence of a perturbation and stressor/stress, including the manner in which the coupled system experiences hazards" **"Sensitivity** of the coupled system to the exposure"

Table 2: Definition of key terms after the IPCC 2007, 2012 and 2014. Words in bold are included as definitions in this table. Words in italic represent additions made in IPCC 2014.

Vulnerability (IPCC 2007, p. 883)	"the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is **expose**d, its **sensitivity**, and its **adaptive capacity**."
Adaptive capacity (IPCC 2007, p. 869)	"The ability of a system to adjust to climate change […] to moderate potential damages to take advantage of opportunities, or to cope with the consequences."
Sensitivity (IPCC 2007, p. 881; *italic 2014, p. 1772)*	"The degree to which a system [*or species*] is affected, either adversely or beneficially, by climate variability or change. The effect may be direct […] or indirect […]."
Disaster risk reduction (IPCC 2012, p. 558; *equiv. 2014, p. 1763*)	"Denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing **exposure**, **hazard**, or **vulnerability**; and improving **resilience**."
Vulnerability (IPCC 2012, p. 564; *italic 2014, p.1775*)	"The propensity or predisposition to be adversely affected." *"Vulnerability encompasses a variety of concepts and elements including **sensitivity** or susceptibility to harm and lack of capacity to cope and adapt."*
Risk (IPCC 2014, p. 1772)	"often represented as probability of occurrence of **hazardous** events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of **vulnerability**, **exposure**, and **hazard**."
Exposure (IPCC 2012, p. 559; *italic 2014, p. 1765*)	"The presence of people, livelihoods, [*species or ecosystems, environmental functions*,] services, and resources, infrastructure, or economic, social, or cultural assets [*in places and settings*] that could be adversely affected."
Hazard (IPCC 2012, p. 560; *italic 2014, p. 1766*)	"The potential occurrence of a natural or human-induced physical event [*or trend or physical impact*] that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, [*ecosystems*,] and environmental resources."
Adaptive capacity (IPCC 2012, p. 556)	"The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities."
Adaptive capacity (IPCC 2014, p. 1758)	"The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences."
Resilience (IPCC 2012, p. 563)	"The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a **hazard**ous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions."
Resilience (IPCC 2014, p. 1772)	"The capacity of social, economic, and environmental systems to cope with a **hazard**ous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation."

vulnerability) has been realized in several reviews (Füssel, 2007; Gallopín, 2006; Hufschmidt, 2011; Preston et al., 2011; Smit and Wandel, 2006; Turner, 2010). Accordingly, it can be summarized that the concepts of vulnerability, risk, resilience, adaptive capacity, and adaptation are not only closely interrelated, but largely overlap, whereby some key terms might be used in the same way, might be labeled differently or even have a completely different meaning. Interestingly, comparing the definitions of the sequent IPCC reports (2014, 2012, 2007) (Table 2), the development of the definitions over time and the influence of different, to some extent overlapping research domains, becomes apparent. Whereas in 2007 vulnerability was defined as function of exposure, sensitivity, and adaptive capacity (cf. Table 2), in 2012 the risk/hazard approach was applied with exposure, hazard, vulnerability, and resilience being central elements, wherein the term vulnerability partially parallels the sensitivity description of 2007 (IPCC, 2012, 2007). Yet, the subsequent IPCC (2014) vulnerability definition represents a mixture of both. As such, the development of the IPCC definitions in recent years illustrates that the fields are more and more merging, borrowing ideas, conceptualizations or methods from one another. However, a new or adapted definition is beyond the scope of this thesis, as the objective of this thesis relates to method development focusing on practical applications. In this regard, bearing the theoretical discussion in mind, the following chapter introduces some vulnerability approaches showing different applications and common research challenges.

3.1 Vulnerability Approaches

A broad range of theoretical vulnerability frameworks/models have been proposed (Metzger et al., 2005; Schröter et al., 2005; Turner et al., 2003a). Vulnerability is a complex, dynamic characteristic of a social-ecological system that is influenced by multiple factors and conflicts inherent to the system, and the specification of the exposure (Adger, 2006; Brooks et al., 2005; Luers, 2005). Short term extreme events as well as gradual changing variables need to be integrated (Brooks et al., 2005; Luers, 2005). Moreover, the feedbacks caused by the reactions of the social and the ecological system need to be taken into consideration (Turner et al., 2003a). Particularly, the impacts of land use change and climate change as well as the associated impairment of ecosystem services and the thread to various species are closely related (Mooney et al., 2009). Furthermore, social vulnerability is often hidden and hard to grasp, since various human aspects and levels of society need to be considered (Fekete, 2009). Against this background, it becomes clear that vulnerability is a multifaceted concept. In that context, a variety of approaches and methods aiming at the spatially explicit mapping of vulnerability evolved. For example, the DIVA tool (Dynamic and Interactive Vulnerability Assessment) includes different climate and socio-economic scenarios as well as adaptation strategies, and therewith enables a comparison of the different vulnerability components (Hinkel and Klein, 2009). Luers (2005) proposed a three dimensional visualization method aimed at the systematic assessment of vulnerable places and people to different impacts (e.g. climatic and economic). The "spatial units of vulnerability" (Kienberger et al., 2010; Leidel et al., 2009) combined land use / land cover data and census data for the spatial modeling of vulnerability independent from administrative boundaries. Schröter et al. (2005) presented a European-wide assessment of the change in ecosystem service supply including multiple global change scenarios (socio-economic, climate, and land use factors) and ecosystem models. They found that changes related to climate and land use resulted in a decreased ecosystem service supply, which in turn increased the vulnerability (e.g. by decreasing water availability). The "social vulnerability index" (Fekete, 2009), a subnational index developed in the context of river floods, enabled the characterization of different social groups in Germany. De Chazal et al. (2008) presented a method that could complement different vulnerability approaches by including stakeholders into the assessment. By means of flexible and transparent matrices, the biophysical properties, land uses, ecosystem services, and stakeholder values were combined to analyze the vulnerability in terms of different land use scenarios. Also Brooks et al. (2005) and Schröter et al. (2004) found that expert based approaches are valuable to validate vulnerability indicators, since the importance of indicators is closely related to local situations.

A comparison of different vulnerability approaches was presented by Wolf (2012). It was stated that in addition to the exposure unit and the entities under consideration, the results could be differentiated in being future-explicit (including scenarios or projections) or present-based (measurements). Hufschmidt (2011) formulated similar differences between studies concerning temporal scales including adaptations or changes. Another distinctive feature was the involvement of local knowledge or stakeholders. For example, De Chazal et al. (2008) extended the vulnerability concept by introducing the term acceptability to measure the different valuations of stakeholders concerning undesirable changes of ecosystem services. As vulnerability is a rather complex and anthropocentric concept, an expert based approach was valuable to take local requirements into account (Leidel et al., 2009). In spite of these different groups of vulnerability studies, the conceptualization of adaptive capacity and related assessments are rather diffuse. This inconsistency may be due to the fact that adaptive capacity is rooted in resilience and vulnerability literature (Engle, 2011). Brooks et al. (2005) argued that the relationship between adaptive capacity and vulnerability depends on time scales. They differentiated between coping capacity for short term and adaptation strategies for long-term reactions. Analogously, Turner et al. (2003b) differentiated the capacity to cope from adaptive capacity (or adaptation strategies), whereby both were considered components of resilience. However, when different case studies are compared (cf. Chapter 3.2), such a temporal specification is often not elucidated, and is therefore only implicit.

It needs to be acknowledged that the body of literature on vulnerability is growing rapidly, reflecting strong development in this area including a multitude of scientific disciplines. At this stage, however, the literature is to some extent inconsistent. Studies often refer to the abovementioned IPCC (2007) definition, but in more simple terms meaning that vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity. Yet, the individual definitions as well as the weighting of the components of vulnerability remain somehow arbitrary. In search of suitable assessment methods focusing on social-ecological systems, in the following section, several case studies are compared focusing on indicators. Hereby, the approach to adaptive capacity is particularly emphasized.

3.2 Indicating Vulnerability Components

The number of European studies that address climate change impacts and adaptation in cities is growing. However, these studies differ substantially with regard to their theoretical or conceptual frameworks, making it difficult to compare approaches and results (Hunt and Watkiss, 2011). Yet, in theory the indicators constructed should allow for comparisons between assessments (Polsky et al., 2007). To structure and compare the indicators used in different studies, the vulnerability scoping diagram by Polsky et al. (2007) was adopted in Figure 2. The scoping study on indicators in vulnerability assessments in urban regions (Schauser et al., 2010) gives an overview on climate change related vulnerability indicators including components of exposure, sensitivity, and adaptive capacity. The illustration in Figure 2 refers to studies conducted in European urban regions with exposure (or hazard) units related to regional climate change models, floods, and heat waves (Birkmann et al., 2010; Brooks et al., 2005; Fekete, 2009; Kienberger et al., 2009; Kropp et al., 2009; Kubal et al., 2009; Lindley et al., 2006; Schröter et al., 2004; Tapsell et al., 2002). The review is not comprehensive, but gives an exemplary overview of vulnerability indicators and therewith provides a basis to reflect the indicators in the light of the social-ecological system approach.

In spite of differences in theoretical foundations, the indicators chosen exhibit parallels in most studies. A number of general conclusions can therefore be drawn after comparing assessment indicators as illustrated in Figure 2. A quite similar set of **sensitivity** indicators was applied in most of the studies. The most commonly used indicators are proportion of elderly people and building type followed by population density and land use (e.g. % of forest). This conformity illustrated that the sensitivity assessment is relatively well developed. Nevertheless, additional indicators differed ranging for example from social hotspots to suitable habitats to land prices.

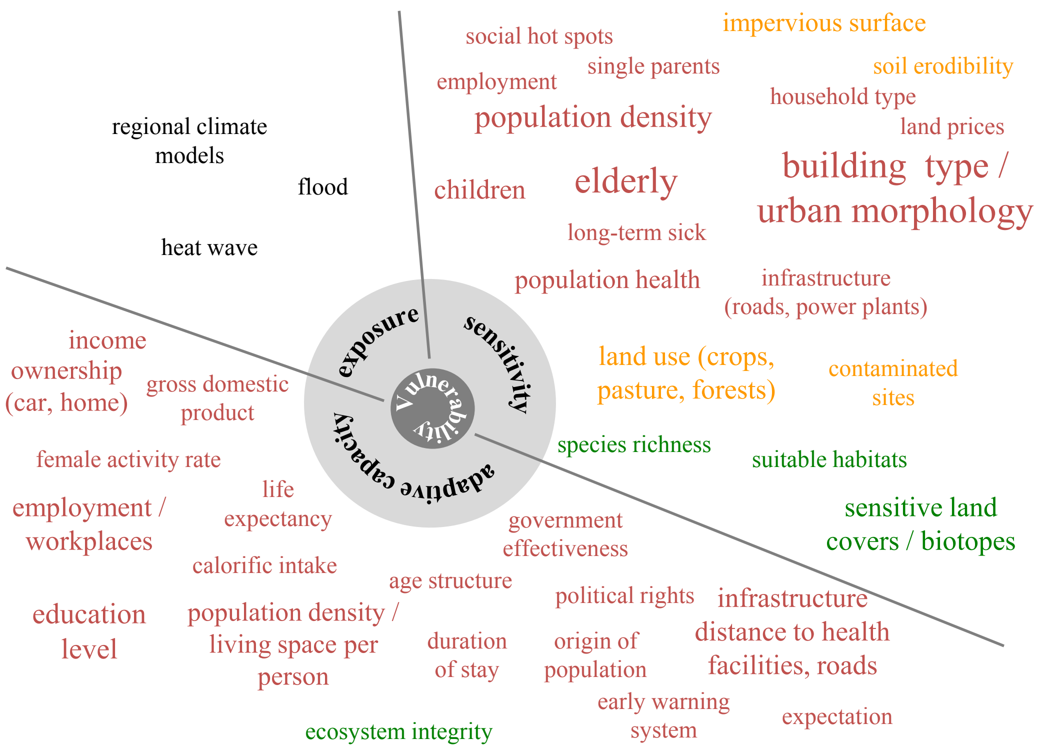

Figure 2: Visualization of indicators for sensitivity and adaptive capacity (exposure solely included as type). Social system indicators are depicted in red and ecological system indicators are depicted in green. Indicators with ambiguous relations are depicted in orange. The bigger the size of the letters, the more frequent the indicators have been used.

In the case of **adaptive capacity**, a diffuse picture was revealed (Figure 2). Adaptive capacity was used in rather different contexts, for example with respect to warning systems and health related issues as well as the capacity to respond to changes (e.g. economically). These indicators are strongly dependent on the objective of the study and on the consequent temporal scale. As such, even if studies applied a similar conceptual definition of adaptive capacity and a similar exposure unit, indicators differed substantially, inhibiting the comparability of results. However, despite featuring different focal points, a number of indicators were used more frequently. The most common indicator for adaptive capacity was education level. In addition, employment and infrastructure (e.g. distance to roads) were used more frequently followed by population density, income, and ownership (Figure 2). Books et al. (2005) validated 46 adaptive capacity indicators by means of statistical analysis (correlation to mortality) and expert evaluation (weighting of importance). They found that in a shortlist of proxy indicators, the key indicators are unlikely to be independent. Moreover, they recognized that the context was highly significant. For example, while isolation and income were decisive factors in Africa, in Norway the infrastructure and efficiency in spatial planning played an important role. However, governance, health, and education were generally of importance (Brooks et al., 2005).

Although almost all studies inherently adopt the **social-ecological system** approach, vulnerability studies differ with respect to the incorporation of multiple dimensions (social, environmental, economic, and political) (Hufschmidt, 2011). The different elements of the social-ecological system were unequally covered by the indicators (cf. colors in Figure 2). Concerning sensitivity, more recent studies integrated both, social and ecological system indicators. In this context, land use and sensitive land cover units as well as species suitability represented ecological systems (cf. Figure 2). Concerning adaptive capacity, however, social system indicators were clearly overrepresented.

The current study led to the assumption that the indicators used for adaptive capacity and sensitivity overlap, since common indicators were found for both dimensions of vulnerability. The specific variables used to indicate the vulnerability elements often do not measure vulnerability directly. Thus there is room for interpretation concerning the key variable and the overall vulnerability (Adger, 2006). In this connection, it should be noted that it is often solely referred to sensitivity and adaptive capacity as the objects of indication (indicandum). Yet, both of these elements are rather complex, thus subsets are established, which are often not specified. To exemplify, considering adaptive capacity, it is assumed that a good economic status increases the ability to react in case of an impact, which is in turn indicated via the income. Likewise, for sensitivity, a low mobility and health status are assumed to have an effect, which is indicated by the proportion of elderly people. At the same time, it is assumed that the elderly people have less access to information, which is a component of adaptive capacity. Thus a better comprehension of the indicandum is required, which could be achieved using the steps of systems analysis (Müller et al., 2016). The signalized overlap between the indicators could be related to conceptualization and/or data availability. Nonetheless, as a consequence, sensitivity and adaptive capacity are likely to be correlated, meaning that indicators such as age are overrepresented in the overall vulnerability. Although this was not necessarily the case in single studies, it is a critical point when comparing and communicating results. Also Polsky et al. (2007) stated that the dimensions of vulnerability often are intimately related and the choice on the positioning of the indicators is somehow ambiguous.

Adaptive capacity is considered to be a key element of vulnerability, alongside sensitivity and exposure (IPCC, 2007). Moreover, adaptive capacity is often described as a decisive aspect of the social part of the system that can positively influence the vulnerability of the overall social-ecological system. In this context, knowledge as the basis for taking decisions and actions in adapting to climate change is a crucial prerequisite for all adaptation efforts. However, even more diverse conceptualizations of adaptive capacity and knowledge exist in addition to a number of vulnerability frameworks (Hinkel, 2011). There is no clarity concerning interrelations between indicators of adaptive capacity and vulnerability or between adaptive capacity and knowledge. Given this lack of clarity in conceptualization, the practicability and applicability of mapping adaptive capacity requires scrutiny. This is of special importance considering that resulting maps are often taken for granted and background indicators are not sufficiently reflected. However, mapping is, as it is understood intuitively, an important communication tool. Mapping vulnerability is an important first step for awareness rising, but due to the inherent uncertainty, the limitations must be communicated clearly. Mapping only the exposure of regions to climate change might include less assumptions concerning statistical analysis, but could also lead to wrong conclusions. To exemplify, regions with high exposure but low sensitivity and high adaptive capacity could be oversupplied considering the distribution of money for adaptation measures. Socio-ecological systems are complex and difficult to capture, hence there can be a dislocation between the climate impact and the social response.

Vulnerability mapping is still under development and as such, several methodological challenges are still to be solved. Common shortcomings in vulnerability studies are the spatial resolution, where more local studies are required, and the dynamics between the social and the ecological system need to be considered (Hinkel and Klein, 2009). However, some indicators are only available at the national level (e.g. GDP) or can hardly be represented by spatially explicit units (e.g. governance structures related to adaptive capacity) (Leidel et al., 2009).

3.3 Key Findings

With the growing evidence on climate change, the field of vulnerability research in recent years has been taken up by many disciplines and thus developed rapidly. In this regard, the vulnerability framework evolved from individual approaches in different disciplines towards expanded vulnerability frameworks, which refer to various approaches. Overlaps between the vulnerability approaches became clear when comparing the indicators used. In this regard, the data set used not only depends on the conceptual framework, but in turn can be used to inform conceptual development in vulnerability assessment (Polsky et al., 2007). Knowledge is an important factor in vulnerability assessment, since it is represented 1) as indicators (e.g. education, access to information), 2) as the consideration of local knowledge by means of transdisciplinary approaches and 3) as the scientific knowledge related to different disciplines. At the same time, the factors knowledge and adaptive capacity as well as adaptive capacity and sensitivity are inherently linked. This leads to the question, how the dimensions of adaptive capacity of a social-ecological system can be captured adequately. Hence, different knowledge forms in various scientific disciplines need to be integrated interdisciplinarily in order to achieve a holistic view on social-ecological vulnerability and associated potential adaptation strategies in urban regions.

In summary, on the one hand, there is a confusion concerning the theoretical frameworks, as there is up to now no generally agreed definition on vulnerability or its components. On the other hand, the merging of different fields bears the opportunity to further develop the framework in an interdisciplinary manner referring to different conceptual approaches and methods. For this thesis, such an initially open approach was of particular importance for the iterative process of developing a social-ecological vulnerability framework based on vulnerability theory (presented here), approaches in ecosystem service research (Chapter 4), and the interdisciplinary process (Chapter 5). From reviewing vulnerability approaches, key implications for the thesis are the importance of clear and transparent reporting of the methods used and related shortcomings, the need for spatially explicit local vulnerability assessments taking both the social and the ecological system into account, and the consideration of different forms of knowledge.

4 THE ECOSYSTEM SERVICE CONCEPT

The ecosystem service concept was already developed in the early 1980s (Ehrlich and Ehrlich, 1981). Yet, the rise of the concept started later after the publications of Daily (Daily, 1997), Costanza (1997), and the Millennium Ecosystem Assessment (MEA, 2005). Since then, research on the ecosystem service concept became very productive with a continuous increase in the number of publications (Martínez-Harms and Balvanera, 2012). Until now, there is a lively scientific debate on the terminology, frameworks, and classification systems (de Groot et al., 2010; Hermann et al., 2011), which resulted in various concepts, frameworks, and assessment approaches. These also related to different terms such as environmental services, landscape services, and ecological services (Lamarque et al., 2011). The following sections first give a short overview on the theoretical basis of the ecosystem service concept. Second, the application of the ecosystem service concept in the urban context is reflected, and third, the practical application considering climate change adaptation is discussed.

4.1 Terminology and Frameworks

The ecosystem service concept represents an application-oriented framework to analyze social-ecological systems. It is inherently interdisciplinary, as it is comprised of elements that refer to natural as well as social sciences. In simple terms ecosystem services are "the benefits people obtain from ecosystems" (MEA, 2005, p. V). In this context, nature is described as being "essential for sustaining and improving human well-being" (Daily et al., 2009, p. 27). This thesis refers to the ecosystem service definition of Burkhard et al. (2012a, p. 2): "Ecosystem services are the contributions of ecosystem structure and function – in combination with other inputs – to human well-being". This ecosystem service definition acknowledges the practical difficulties in the separation of human inputs and nature based contributions to ecosystem services. Human wellbeing is a multifaceted concept that can be approached differently. In this thesis, the classification of Summers et al. (2012) was used distinguishing 1) basic human needs, 2) economic wellbeing, 3) environmental needs, and 4) subjective wellbeing or happiness.

The ecosystem service cascade (Haines-Young and Potschin, 2010) provides a framework for the description of the link between ecosystems and human-wellbeing. In the cascade, as depicted in Figure 3a, landscape structures and processes exhibit functions that are regarded as services when used by people. Depending on the context (e.g. places and society), different benefits and values are assigned to the services (Haines-Young and Potschin, 2010). The first two elements of the cascade refer to ecosystems and biodiversity (Figure 3, green), the benefits and associated values refer to human well-being (Figure 3, red), and the ecosystem services represent the linking element (Figure 3, blue). The cascade could also be seen as "stairways" (Spangenberg et al., 2014) beginning at the value end.

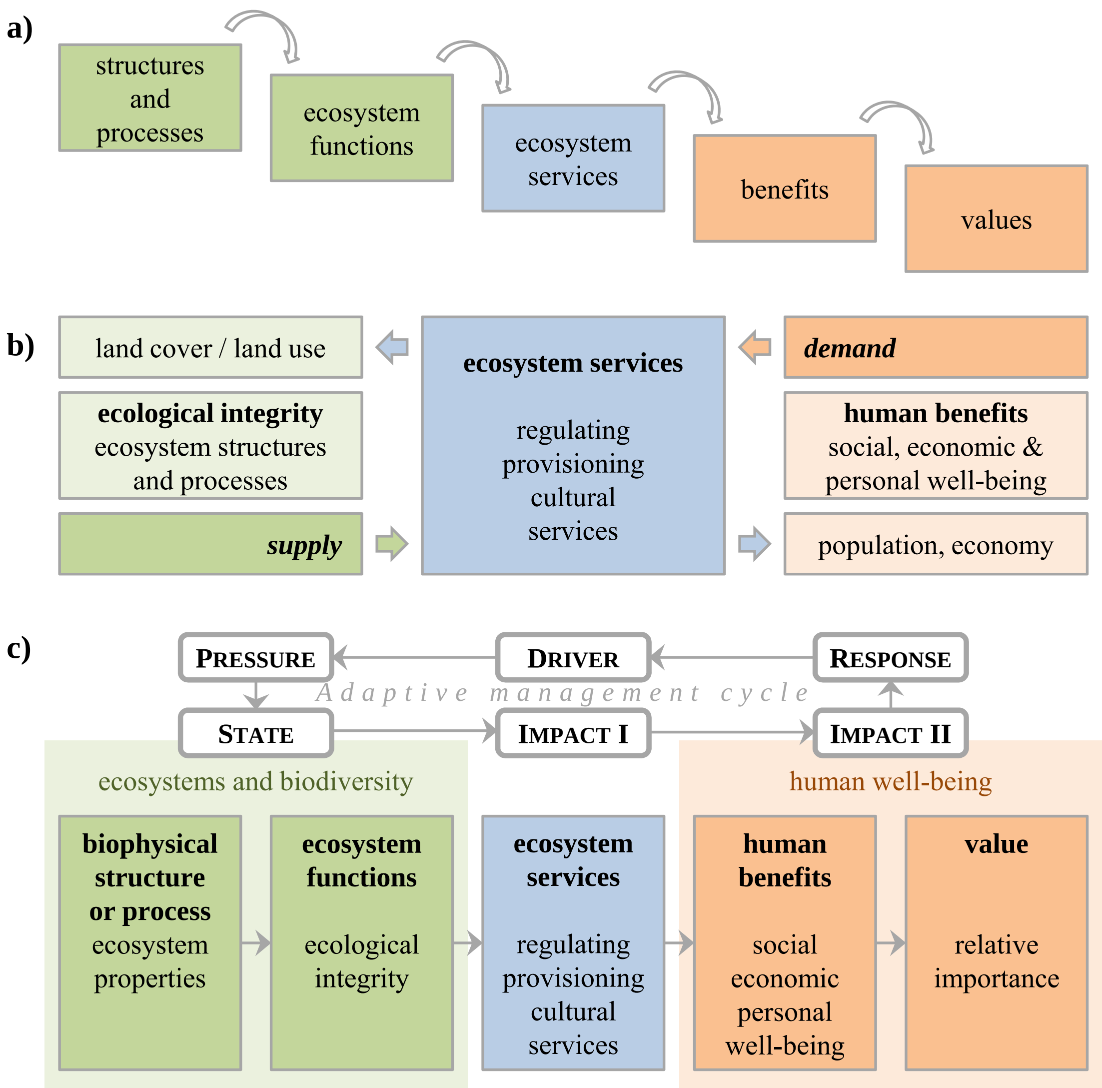

Figure 3: Description of the ecosystem service concept illustrating a) the ecosystem service cascade adopted from Haines-Young and Potschin (2010), b) the supply-demand approach adopted from Burkhard et al. (2012b), and c) the Driver-Pressure-State-Impact-Response (DPSIR) context adopted from Müller and Burkhard (2012)

The cascade is used in different contexts as a starting point followed by detailed definitions of the elements and their operationalization for the assessment. In this context, it is difficult to separate ecosystem functions (as in Figure 3 a) from ecosystem structures and processes as well as from ecosystem services. Focusing on the central element, Burkhard et al. (2012b) circumvented the problem with a framework that differentiates between ecosystem service supply and demand (Figure 3b). Therein, the supply is defined as “the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period” (Burkhard et al., 2012b, p. 18). The demand refers to the sum of ecosystem services that are “currently consumed or used in a particular area over a given time period” (Burkhard et al., 2012b, p. 18). This approach allows to consider landscape change in a market situation of demand and supply. By this means, resource allocation, such as a demand from outside a planning region can be incorporated (Termorshuizen and Opdam, 2009).

In addition, it has been shown that the ecosystem service concept can be applied in an adaptive management cycle (Figure 3c). Herein, Müller and Burkhard (2012) referred to the DPSIR framework (cf. Chapter 6). The basic idea is that the social system produces pressures (through e.g. development and consumption), which could affect the state of the system i.e. the ecosystem structures and processes as well as ecosystem functions. Changes in the state of the system could result in impacts related to the provision of ecosystem services and consequently human well-being. Finally, the response refers to actions taken to minimize the negative impacts (Müller and Burkhard, 2012). This application shows the typical position of ecosystem services in indicator frameworks, which can be approached from different viewpoints concerning for example the evaluation of responses or the characterization of impacts. Research challenges relate to the complexity within the components and the linkages between the components (Müller and Burkhard, 2012).

In that context, the definition of ecosystem services, their classification, and the development of indicators depends on the characteristics of the system under consideration, which in this thesis are urban regions. Furthermore, it depends on the potential application in practice, where the focus is set on climate change adaptation, here. These aspects are elaborated in the following sections.

4.2 The Ecosystem Service Concept in the Urban Context

In the last years, more and more ecosystem service studies were performed in urban environments (Haase et al., 2014). Yet, urban land use exhibits unique characteristics, which are according to Haase (2014): a) A high share of artificial surfaces, which are unlikely to revert back to pre-urban conditions; b) A high degree of and variability in imperviousness; c) A high multifunctionality that varies across vertical and horizontal dimensions. As such, the application of the ecosystem service concept in urban environments needs to be reflected carefully (Beichler et al., 2017)[1]. On the one hand, there is a general acceptance that the ecosystem definition is very flexible and diverse conceptualizations exist (Currie, 2011; Pickett and Cadenasso, 2002), thus it could be applied in the urban context. On the other hand, it can be argued that the ecosystem service concept could promote an exploitative human-nature relationship (Schröter et al., 2014). Thus, regarding all kinds of urban structures as ecosystems could dissent from the normative principles (as described in the introduction of Chapter 4) of the ecosystem service concept. Against this background, Beichler et al. (2017) provide an overview on approaches and discuss the **handling of urban structures** as subjects capable of providing ecosystem services or not.

The paper discusses different **ecosystem definitions** in the context of urban ecosystem services from the initial definition proposed by Transley (1935) to the conception of novel ecosystems (Hobbs et al., 2006; Kowarik, 2011). It is summarized that in general a city could be defined as either one ecosystem or an assembly of ecosystems (after Bolund and Hunhammar, 1999). The individual entities of a city could be referred to as remains of natural landscape, cultural landscapes, horticultural designed green spaces or specific urban nature (four types of nature in cities after Kowarik, 1992) and some are no ecosystems at all. A city as a whole might be best described as “Total Human Ecosystem” (Naveh, 2000) or by focusing on ecological processes instead of entities (Currie, 2011).

In practice, altered ecosystems could be characterized by management or land use types (de Groot et al., 2010). Thus, the different **land use types in urban regions** namely the

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[1] cf. „

Vorabveröffentlichungen der Dissertation“ page 1 classes housing, industry, transport, urban blue and green as well as urban agriculture were reflected considering types of ecosystems with regard to remaining natural components, degree of human modification, and human input (Beichler et al., 2017). In general, urban land use classes represent a pattern (not a single patch) and due to the vertical dimension, one patch could include built up structures and ecological structures at the same time. As such, the problem of scale needs to be considered not only in the theoretical definition of an ecosystem, but also in the practical application considering ecosystem service indicators (Beichler et al., 2017).

In urban environments, the fact that **humans are an interactive part** of the system becomes apparent looking at the different levels of ecosystem transformation, the different forms of management, and levels of input influencing abiotic and biotic components and therewith ecosystem service provision (Kowarik, 2011; Mooney et al., 2009). The structures that need to be dealt with in the urban context referring to different ecosystem definitions could be classified (Beichler et al., 2017) into: 1) *Near natural ecosystems* (e.g. lakes, forests); 2) *Managed ecosystems* – still based on original ecosystem components continuously influenced and managed (e.g. parks, gardens); 3) *Overbuilt (eco)systems* – built up areas, where some original ecosystem components and processes are retained (e.g. parking places with grass pavers); 4) *Constructed (eco)systems* – man-made ecosystem structures that form artificial habitats (e.g. green roofs). Although, these classes are not mutually exclusive, they allow for a structured discussion of the consistency with the different frameworks of the Millennium Ecosystem Assessment (MEA, 2005), the EPPS framework (Ecosystem Properties Potentials Service) (Bastian et al., 2013, 2012b), the ecosystem service cascade (Haines-Young and Potschin, 2010), and the proposed frameworks of Burkhard et al. (2012a, 2012b) and Müller et al. (2010b). The discussion revealed that in principle all frameworks could be applied in the urban environment, as they do not refer to a specific ecosystem definition, but take biophysical structures and processes (see also Figure 3) as a starting point.

From the conceptual point of view, any system could be the object of an ecosystem service study as the degree of human modification and input should be considered during assessment, which would allow to distinguish between ecosystem services and man-made services (Beichler et al., 2017). However, taking human effects on ecosystems, their services, and related values into account, as well as separating human input and the service provided by the ecosystem itself, becomes in practice a yet to be solved, complex scientific challenge (Burkhard et al., 2014; Daily et al., 2009; de Groot et al., 2010).

The consideration of **human benefits and values** is one of the main principles of the ecosystem service concept designed to analyze social-ecological systems (Spangenberg et al., 2014). In that context, as pointed out in the introduction (Chapter 2), urban regions represent interesting laboratories to study the complex interactions in social-ecological systems. Reflecting the relative importance of different urban structures by using the ecosystem service concept could be particularly insightful due to the close spatial proximity of supply and demand, the scarcity of ecosystems, and the high population density (Beichler et al., 2017). The application of the ecosystem service concept in urban environments could give ecological aspects a higher status in decision-making, which reflects a basic objective of the ecosystem service concept explicitly addressing the intrinsic value of nature (Schröter et al., 2014).

In recent years, there has been a conceptual shift towards the process-oriented approach in defining ecosystems (Currie, 2011). In this context, it is of high importance to consider the issue of long-term ecosystem integrity (Currie, 2011; Müller et al., 2010b), characterizing the **ecosystem state**, in order to assure the consistency with the normative principles of the ecosystem service concept (Beichler et al., 2017). Ecosystem integrity refers to the self-organizing capacity of the system, which can be described by means of several structural and functional variables (Burkhard et al., 2012b; Kandziora et al., 2013; Müller and Burkhard, 2012; Müller et al., 2010a).

These theoretical considerations, however, are countered by the considerable challenges researchers are facing during the **practical ecosystem service assessment.** Various assessment approaches have been developed, on the one hand focusing on urban green areas or green infrastructure (Bezák and Lyytimäki, 2011), such as urban parks (e.g. Breuste et al., 2013b) or green roofs (e.g. Oberndorfer et al., 2007). On the other hand, there are land use and land cover based assessments covering the overall urban region (for example Burkhard et al., 2010a; Larondelle et al., 2014). Moreover, participatory approaches (for example Kabisch and Haase, 2014; Voigt et al., 2014) were applied with increasing frequency in the recent years. This diversity of approaches indicates various ways of dealing with urban structures, which however had rarely been made transparent in case studies (Beichler et al., 2017). This need for a more detailed and transparent reporting has been noticed by other authors as well (Martínez-Harms and Balvanera, 2012; Seppelt et al., 2012). Based on the data used and the indicators and methods developed, the implicit theoretical considerations or practical requirements were discussed. It was found that challenges were related to the quality of data (e.g. related to land use/land cover classification (Breuste et al., 2013a)), to statistical methods (e.g. aggregation (Scholes et al., 2013)), and to the integration of different datasets (subsystems social, ecological (Müller et al., 2010b; Scholes et al., 2013), and the built up environment (Moffatt and Kohler, 2008)) as well as to the dealing with participatory data (for detailed description see Beichler et al., 2017). Against this background, it became apparent that it is on the one hand technically challenging to distinguish between different types of urban structures. On the other hand, comprehensive approaches are needed to identify the underlying mechanisms that characterize the complex dynamic interactions between social and ecological structures and processes (Alberti, 2005; Mörtberg et al., 2012; Reyers et al., 2013).

In summary, **urban environments represent an extreme case** that calls special attention to the consideration of human input, modification, ecosystem state, and social-ecological interactions. These aspects are mostly covered in the theoretical frameworks, but assessment methods need to be further developed in order to take them systematically into account. Almost all ecosystems on earth have been heavily altered and are impacted through human activities, which resulted in substantial loss of ecosystems and their services (MEA, 2005; Mooney et al., 2009). Thus, the identified challenges hold true for the application of the ecosystem service concept in general. Nevertheless, ecosystem service assessments provide valuable information to assist in urban planning through the identification of intangible values of ecosystems (Daily et al., 2009). It has been shown that urban areas can provide various different ecosystem services at multiple scales (Bezák and Lyytimäki, 2011; Bolund and Hunhammar, 1999; Haase et al., 2014). Although urban areas cannot substitute for the functioning of natural ecosystems (Kowarik, 2011), urban ecosystem services are of high relevance considering the wellbeing of the population as well as the ecological connectivity in the overall urban region. Hereby, ecosystem service maps can support planning processes through the identification and framing of problems (Hauck et al., 2013). The application of the concept in the context of climate change represents a special case, for which the associated practical implications for this thesis are described in the following chapter.

4.3 Application in the Context of Climate Change

Considering climate change, the ecosystem service concept could assist the development of ecosystem based adaptation and management approaches (Chapter 2 Introduction). Ecosystem service modeling enables the visualization of the functioning of the landscape and potential future development. The ecosystem service concept could be implemented in the **planning** sector, since herein norms and rules for the decision making process related to the use of natural resources are established (Cowling et al., 2008). Yet, a lot of ecosystem services receive no consideration in planning and decision making, inhibiting the development of multifunctional landscapes (de Groot et al., 2010). Often, the significance of an ecosystem service is only recognized after it has been lost (Daily et al., 2009). In the context of climate change, several land use forms and their associated services could play a special role. For example, natural areas that retain water, especially close to settlements, could be of particular importance considering the predicted increase in extreme precipitation events.

As pointed in the previous chapters, urban regions represent interesting laboratories to study **interactions in social-ecological systems**. However, vulnerability studies tend to focus on the social system (cf. Chapter 3.3), thus the population's vulnerability. Whereas, ecosystem service studies tend to focus on the supply side of the ecosystem services cascade (Reyers et al., 2013). In the context of climate change, on the one hand, the ecosystem service supply is likely to change through impacts on the ecological system. On the other hand, due to impacts on the population (e.g. caused by heavy rain), the demand could change (detailed description in Chapter 6). However, the application of the ecosystem service concept to evaluate impacts (Chapter 4.1, Figure 3c) is difficult, as the linkages between the components are not completely understood yet. A major challenge in ecosystem service research is to establish the link between different groups of the population and ecosystem services (Daily et al., 2009; Granek et al., 2010). This direct link between the social and the ecological system is of particular importance to combine the vulnerability and the ecosystem service concept. Understanding the interactions between the social and ecological system under climate change is essential to develop enhanced adaptation measures. Against this background, it becomes clear that method development is needed to approach these issues. In this regard, the different groups of ecosystem services and supply-demand interactions are described in detail in the following sections.

4.3.1 Implications regarding Ecosystem Service Categories

Over the years, several different ecosystem service classification systems have been proposed (e.g. de Groot et al., 2002; MEA, 2005). In an attempt to integrate the different perspectives, the common international classification of ecosystem services (CICES) has been proposed and is as still subject to continuous development (Haines-Young and Potschin, 2013). In general, the three main groups provisioning, regulating, and cultural ecosystem services can be distinguished (Crossman et al., 2013; Hermann et al., 2011; Martínez-Harms and Balvanera, 2012). Supporting services, which maintain the generation of all ecosystem services (MEA, 2005), are often additionally mentioned. This group, however, largely overlaps with the assessment of basic ecosystem functions and the integrity approach (cf. Chapter 4.1 and 4.2).

Provisioning ecosystem services relate to products derived from ecosystems, such as wood, fiber and agricultural goods (MEA, 2005). Thus, the generated benefit can be perceived directly through the value of the products. However, for studies at the local scale it has to be acknowledged that urban regions depend on worldwide teleconnections (Seto et al., 2012). Hence, under climate change, the supply of provisioning services could be impacted, but changes do not essentially relate to the local demand (e.g. considering food supply).

Regulating ecosystem services refer to benefits obtained through the regulation of ecosystem processes such as air quality, climate, and water regulation (MEA, 2005). Regulating ecosystem services play a special role in the context of climate change. Measures to increase regulating services could decrease the vulnerability. Yet, since regulating services are perceived indirectly, the link to different groups of the population is difficult to establish. In addition, regulating services are less suitable for participatory assessments (Brown et al., 2012). However, in the last years, the group of regulating service was studied more frequently than the others, particularly in urban environments (Haase et al., 2014; Martínez-Harms and Balvanera, 2012). Thus, there is a sound knowledge base, which enables to draw on a broad range of literature using indicators to assess regulating services.

Cultural ecosystem services (CES) refer to benefits derived from the relationship between humans and ecosystems, such as recreation, education, and aesthetics. The group of CES has been studies less frequently then other ecosystem services (Haase et al., 2014; Martínez-Harms and Balvanera, 2012). Although in the last years the topic gained more attention, most studies focused on recreation. Thus studies including services like cultural identity and spiritual values are largely absent (Chan et al., 2012). The insufficient consideration of CES in assessment relates to difficulties in evaluation and their intangible and subjective nature (Chan et al., 2012; Daniel et al., 2012). Yet, this very dependence on social constructs enables to identify social-ecological linkages and to bridge the gaps between disciplines (Milcu et al., 2013). As the benefits derived from CES are directly perceived, they are particularly suitable for stakeholder involvement and provide the opportunity to study the link to different groups of the population. For both, ecosystem service assessment and vulnerability assessments (cf. Chapter 3.1), it has been reported that, to take local characteristics into account, stakeholder participation is crucial (Hernández-Morcillo et al., 2013; Hunt and Watkiss, 2011; Hutton et al., 2011). Thus, focusing on CES has a high potential finding integrated assessment approaches. As such, in the quantitative assessment of this thesis, a participatory assessment approach focusing on CES was undertaken in order to bring local experiences from stakeholders into a spatial context (Brown et al., 2012; Fagerholm et al., 2012) and to evaluate the relative importance of ecosystem services and the relationship to human wellbeing (Maynard et al., 2011).

4.3.2 Supply-Demand-Interactions

It has been shown that the provision of ecosystem services differs along the urban-rural gradient (Kroll et al., 2012; Larondelle and Haase, 2013). This underlines the fact that ecosystem services are supplied locally, but could generate benefits at other scales (de Groot et al., 2010). This is of special importance when studying the linkages of social-ecological systems in urban regions considering interactions between the city and the hinterland. In recent years, the number of case studies considering also the ecosystem service demand is increasing, whereby different conceptualizations of demand can be distinguished namely risk reduction, preferences, consumption, and direct use (Wolff et al., 2015). The assessment of ecosystem service providing areas and benefitting areas enables the evaluation of matches and mismatches between supply and demand (Burkhard et al., 2012b; Schulp et al., 2014). Combining the spatial pattern of supply and demand could help identifying priority areas for investments (Stürck et al., 2014). However, further research is required to understand the feedbacks between supply and demand considering e.g. spatial dynamics (Wolff et al., 2015). In the context of climate change adaptation in urban and regional planning, the spatial relations between the city and the hinterland are of special interest. Uncovering these relations, could help to locate areas were adaptation measures have the highest effect. Moreover, studying the interrelations between supply and demand areas could assist in identifying the impact on the population related to the loss or decrease of distant ecosystem services.

4.4 Key Findings

The ecosystem service cascade and the supply-demand approach are versatile starting points for the operationalization of the ecosystem service concept for practical assessments. The ecosystem service concept aims at the internalization of the benefits derived from ecosystems into decision making processes. A detailed elaboration of the application of the ecosystem service concept in urban environments was undertaken (summarized based on Beichler et al. (2017)) showing that the concept does not reach its limits in urban environments. It rather points at practical challenges related to the ecosystem service concept in general. These challenges range from the problem of scale considering different land use types in urban regions, to the systematical consideration of humans as interactive parts of the system, to the need for a more transparent reporting of assessment methods.

Main research needs relate to the linkages between the components in the ecosystem service concept particularly the interactions in the social-ecological system. Two dimensions have been found to be of particular importance in the context of climate change: 1) The **categorical link** referring to the supply of ecosystem and the demand of different groups of the population considering social factors. 2) The **spatial link** between the ecosystem service supply areas and the location of the beneficiaries. These two dimensions were further explored in the practical part of this thesis. Thereby, the focus was set on CES, as they have been identified to be most suitable to study the link between supply and demand. Additionally, the required assessment methods show parallels to vulnerability assessment. Nonetheless, due to their importance in the context of climate change, the results are discussed reflecting upon regulating services as well. Furthermore, a focus was laid on differences between the city and the hinterland, as these bear important implications to inform urban and regional planning with regard to adaptation (see also scales in the interdisciplinary context described in Chapter 5.2.3).

The ecosystem service concept has already been applied in a DPSIR context (Chapter 4.1). Yet, to combine the ecosystem service concept and the vulnerability concept, while equally considering the social and the ecological system, a comprehensive methodological approach is required. This includes a combination of the theoretical frameworks (Chapter 6) as well as the development of assessment methods (Chapter 7.3 and 7.4).

5 THE INTERDISCIPLINARY RESEARCH PERSPECTIVE

In order to manage the interdisciplinary challenge of climate change, approaches that integrate the different scientific disciplines and conduct transdisciplinary research are needed (Deppisch and Hasibovic, 2013). The thesis project was embedded in the wider research context of the project plan B:altic. The overall objective of plan B:altic was the development of climate change adaptation strategies in the context of urban and regional development in urban regions at the Baltic Sea coast taking a social-ecological approach. Although this thesis is a discrete project with independent research questions, the individual components of vulnerability are inherently linked to the topics of the other subprojects of plan B:altic, particularly climate change modeling, knowledge exchange, governance, and planning instruments. Hence, for vulnerability research in the context of climate change, the development of an interdisciplinary understanding of the different research domains, contexts, and applications is crucial (Bhaskar et al., 2010). As such, the process of interdisciplinary integration within the project played an essential role in building a strong research basis facilitating a comprehensive and interdisciplinary view on the topic of vulnerability. Two parallel processes can be distinguished, the development of the bridging concept for the project plan B:altic and the manifestation of aspects of the bridging concept within the individual subprojects (Beichler et al., 2014). In this regard, the conception of the thesis had a major influence on the process itself and at the same time benefitted from it.

5.1 Social-ecological Resilience – The Interdisciplinary Process

Interdisciplinarity is a “lively process” (Buller, 2008) that can take many forms depending on the scope, the type of interaction (empirical, methodological, theoretical), and the goal (Huutoniemi et al., 2010). In the project plan B:altic, the concept of resilience was used to integrate approaches and perspectives of several disciplines, such as earth system science, spatial planning, landscape ecology, geography, and communication sciences. The interdisciplinary process (summarized based on Beichler et al. (2014) in Figure 4) started with the examination of different resilience concepts (Adger, 2006; Adger et al., 2005; Carpenter et al., 2001; Folke, 2006; Füssel, 2007; Gallopín, 2006; Gunderson and Holling, 2002; Smit and Wandel, 2006; Walker et al., 2006, 2004). It was found that the concept of social-ecological resilience (Folke, 2006) represents a valuable basis to integrate the different disciplinary perspectives,

examination of
various resilience concepts

social-ecological resilience
as basis to integrate disciplinary perspectives

working definition: *"Social-ecological resilience is the capacity of an urban region to absorb uncertain climatic stimuli and their effects so as to maintain the essential social and ecological functional and structural properties, while undergoing change."*

basic elements:
(1) resilience as a capacity (Walker et al. 2004)
(2) contextualized notion (resilience of what to what) (Carpenter et al. 2001)
(3) change and complexity intrinsic to social-ecological systems (Folke 2006; Adger 2005).

contested issues

- defining structural and functional properties of the social-ecological system
- degree of self-organization
- temporal and spatial scales
- interpretative/symbolic dimensions
- degree of normativity
- tension between change and persistence, transformative change
- notions of adaptive capacity
- political/power dimension
- knowledge
- uncertainties

→ identification and acknowledgement of the variety of meanings and of possible structures
→ from conceptual precision to vagueness
(Strunz 2012)

social-ecological resilience thinking
(Folke et al. 2010)
• emphasizing the social-ecological context
• social-ecological resilience thinking as an endpoint: basis or normative setting for discussing adaptation measures

Figure 4: The interdisciplinary process adopted and summarized based on Beichler et al. (2014)

due to its systemic character, the strong interdisciplinary character (bridging natural and social sciences), and the potential to deal with uncertainty and nescience (Beichler et al., 2014).

In order to find a joint definition of social-ecological resilience (cf. Figure 4), the individual elements of the social-ecological resilience definition, such as capacity or essential social and ecological properties, were discussed in detail. This enabled the exploration of assumptions and perspectives of all disciplines involved. The interdisciplinary dialog revealed that the general principles of existing social-ecological resilience concepts are adoptable by all disciplines involved, but the precise meaning of several elements differed considerably among disciplines (cf. contested issues in Figure 4). Although for some factors a remarkably degree of convergence was achieved, some issues (e.g. “what should be maintained”) concerned the conceptual core of the disciplines involved and thus needed to be addressed differently. As a result, the objective to find a joint definition of social-ecological resilience, that is adoptable by all disciplines involved, proved to be unachievable. To acknowledge the variety of meanings, the focus was shifted to the conceptual vagueness (Strunz, 2012) using the concept of social-ecological resilience thinking (Folke et al., 2010). Nevertheless, the conceptual precision of a social-ecological resilience definition facilitated the extensive exchange of disciplines by means of cognitive and social functions (Beichler et al., 2014). This resulted in an enhanced interdisciplinary understanding of the social-ecological resilience elements. The contested issues are elaborated in the next chapter focusing on implications for this thesis.

5.2 Interdisciplinary Implications

The main aspects of the resilience concept used in the other subprojects (summarized in Table 3, see Beichler et al. 2014 for a detailed description) give an overview of the different disciplinary backgrounds and notions of resilience. What all projects had in common, was the focus on climate change adaptation in the context of urban and regional planning, whereby urban regions are understood as social-ecological systems.

The contested issues (as displayed in Figure 4) in principle could be described as key issues that overlap between the disciplines involved with differing implications considering concept, method, and application. As the vulnerability and the resilience concept are closely related, discussing these overlaps in the interdisciplinary context proved a valuable asset in the framing of the key objects, namely the elements of vulnerability, the urban region, and the social-ecological system.

5.2.1 Climate Change Impact

One element of the vulnerability assessment (cf. Chapter 3) the exposure as part of this thesis overlapped with the study on climate change modeling as both deal with climate change impact assessment. In climate change literature, "climate change impact" can have multiple meanings, which could be related to different vulnerability components. Through the interdisciplinary work dealing with the question "What does impact really mean?" it became clear that there is a need for a more precise vocabulary. Two different meanings of climate change impact were identified. First, climate change modeling investigates the development of the regional climate, therewith the *effect* of global climate change on the regional climate. Second, vulnerability research studies the *manifestation* of the *effect* of climate change on the social-ecological system. Hence, in the context of this thesis, the exposure was defined as an internal property (the regional effect driven by external factors) of the system describing the spatially explicit,

Table 3: Summary of the different aspects of resilience that are of importance in the individual subprojects of plan B:altic (a-f) representing different scientific disciplines (summarized based on Beichler et al. 2014)

***a)** climate change modeling*	• uncertainty related to future development of climate change (including scenarios) • uncertainty intrinsic to the models • uncertainty and complexity considering urban spatial development and its feedback to local climates • need for clearly defined spatial and temporal scales
***b)** instruments & methods in urban & regional planning*	• open notion of resilience thinking shows parallels in planning theory (non-linearity, uncertainty, self-organization, learning processes and adaptive capacity) • complexity and dynamics of future developments considering implications for spatial planning
***c)** governance*	• normative assumption: multilevel governance structures can positively influence adaptive capacity, enhancing the resilience of social-ecological system • governance structures as part of the social-ecological system (actions of stakeholders and relations between them influence the state of the system)
***d)** knowledge*	• concept of social-ecological resilience highlights change and social learning • assumption that social-ecological systems can adapt and change only through learning (generating and exchanging knowledge) • knowledge generation and social learning contribute to building adaptive capacity
***e)** communication*	• using the concept of resilience thinking leads to a different nature and perception of adaptation • resilience influenced by notions of change (transformative), complexity, social construction, and power
***f)** ethics*	• complexity and learning to live with change • perspective of social and ecological interdependencies • considering potential transformation of essential functional and structural properties

region-specific manifestation of climate change, namely the nature and degree to which ecosystems are exposed to change (see also Chapter 6).

The overlap with the subproject of climate change modeling resulted in a discussion about how the vulnerability could be framed in order to be able to include updated climate change modeling results. Thus, the exposure element needs to be implemented in a transparent way in order to be adaptable to new findings, which would also enhance the transferability into practice dealing with multiple climate change scenarios. Hence, here the vulnerability assessment includes information on the nature of the exposure (vulnerability to what, e.g. increased heat island effect). That way, the results from climate change modeling could be used in addition to describe the exposure in a spatially explicit way. However, if no spatially explicit information on the exposure is available, all areas are assumed to be exposed equally focusing on the link between the social and the ecological system and associated consequences, thus the sensitivity element. The sensitivity describes the potential susceptibility to change of land use, ecosystem services, and population wellbeing as a response to exposure.

5.2.2 Adaptive Capacity in the Interdisciplinary Context

Adaptive capacity is of special importance, as it can have differing connotations in the context resilience, vulnerability, and adaptation (cf. Table 3 and Table 2 p. 19). Adaptive capacity is an inherent property of the overall system, but at the same time influences vulnerability directly. Moreover, as pointed out in Chapter 3, adaptive capacity is directly related to the vulnerability as well as the resilience concept. The interdisciplinary research process widened the perspective on how adaptive capacity in the context of a vulnerability framework could be approached.

Looking at the manifestation of the resilience concept within the individual subprojects (Table 3), different aspects that are captured by adaptive capacity can be identified. On the one hand, the ability of a system to self-organize changes through time with accumulation of information (Table 3d and e) was described as part of adaptive capacity. On the other hand, the increasing connectedness (Table 3b and c) was related to adaptive capacity. As a result, particularly the aspects of governance and knowledge exchange were included in the reflection of the framework developed in this thesis (further elaborated in section 5.3).

5.2.3 Scales

The discussion of the contested issues related to spatial and temporal scales was inherently linked to the disciplinary definitions of the social-ecological systems' structural and functional properties (Figure 4). Concerning the temporal scales, different time frames could be identified. The temporal scale of climate change models refers to at least 30 years, whereas the time horizon in planning is restricted to the validity of plans (5-7 years). Whilst the vulnerability assessment in turn was related to the time steps, at which data for a spatial analysis of the region was available. In addition, vulnerability assessments need to integrate short-term extreme events and gradual changing variables (Brooks et al., 2005; Luers, 2005) (see also Chapter 3). Due to data availability, the practical application of the framework in this thesis is restricted to one point in time, but considers two different temporal levels in terms of potential exposure: short-term extreme events (drought, heat) and a slow continuous long-term process (sea level rise).

Adaptation measures derived through vulnerability analysis should be relevant to urban and regional planning. Furthermore, as pointed out in Chapter 4, there are multiple methods to assess ecosystem services. Hereby, the scale of assessment is of crucial importance for the outcome, as an ecosystem can comprise many different spatial levels (Hermann et al. 2011). Here, the assessment at the landscape level was adopted, wherein ecosystem services are assigned to different land uses. In this context, is has to be acknowledged that land use has an effect on the regional climate (Potschin, 2009; Schröter et al., 2005). Consequently, land use plays a crucial role in discussing adaptation as a key variable that a) influences the regional effect of climate change, b) is used to assess the spatial distribution of ecosystem services, and c) is a main aspect in urban and regional planning. Thus, the spatial scale was related to data availability in the case study region and the spatial scale of land use plans. In addition, the regional ecosystem service supply might lead to benefits at other scales (de Groot et al., 2010). In former times, this relationship was rather prominent in urban regions, farmers in the hinterland produced the food demanded by the population of the city. Nowadays goods are traded throughout the world and the direct observable link is missing (cf. Chapter 4.3). Nevertheless, services like recreation, air filtering, and groundwater filtering are still produced mainly in the hinterland and used by the city's population. Thus, to set the spatial boundaries for the practical application of the framework, it was important to analyze urban regions as a whole to consider the interactions between the city and its hinterland, which does not necessarily correspond to the spatial scale of land use plans.

5.3 Social-ecological System Approaches and Resilience - From Complexity to Practicability

Social-ecological system approaches stress the fact that human actions and social structures are integrated into the ecological system. Thus, a dependent consideration in the context of vulnerability assessment is inevitable (Adger, 2006; Gallopín, 2006). Particularly the dynamic interactions between the subsystems are essential for future development (Gallopín, 2006). However, social-ecological systems are complex and hard to assess. There are multiple and overlapping, so called nested scales, within social-ecological systems (Gunderson and Holling, 2002). The challenge is to analyze the dynamics between and within both systems in a rather simple way, while making sure that the complexity of the overall system is included (Kluvánková-Oravská and Chobotová, 2007). A general framework for the identification of subsystem variables of social-ecological systems was proposed by Ostrom (2009). Although it was developed to analyze the sustainability of social-ecological systems in the context of natural resources, Ostrom's framework can be applied using different theories and approaches and supports the process of conceptualization (Schlüter and Hinkel, 2014). As such, it helped to identify important factors to be included in the vulnerability analysis of this thesis, namely users, resource system and units, governance, and social-ecological interactions.

Clearly, the resilience concept opens up a wide perspective to approach complex coupled social-ecological systems. Nevertheless, the approach needs to be aligned to the timeframe and resources available within the limited time of a thesis. As mentioned in Chapter 3, the concepts of vulnerability and resilience are closely related. However, merging them is not straightforward as the concepts are coalescing, complementary, and conflicting at the same time (for a detailed review see for example Gallopín, 2006; Miller et al., 2010; Turner, 2010). In general, vulnerability assessments seek to identify the weakest parts of the system, whereas resilience refers to characteristics making the system withstand disturbances (Turner, 2010). Vulnerability might be simply described as antonymic to resilience (Folke, 2006). However, this definition falls short as "a resilient system is less vulnerable than a non resilient one, but this relation does not necessarily imply symmetry" (Gallopín, 2006, p. 299). As such, in the context of this thesis, resilience is seen as overall system property influencing its behavior in case of change. The vulnerability is embedded as one characteristic of the social-ecological system influencing resilience, explicitly not antonymic to resilience. The conceptual overlap between the concepts in the context of this thesis is visualized in Figure 5 (cf. also the interdisciplinary notions in Table 3).

Resilience is an internal property of the system (excluding exposure) and directly related to (or even the same as) adaptive capacity (Gallopín, 2006). Interestingly, the framework of Turner et al. (2003a) conceptualizes vulnerability as a function of exposure, sensitivity, and resilience (including coping, impact/response, and adjustment/adaptation), which are all linked to factors outside the system operating at various scales. In the context of resilience, the term adaptive capacity is defined as the

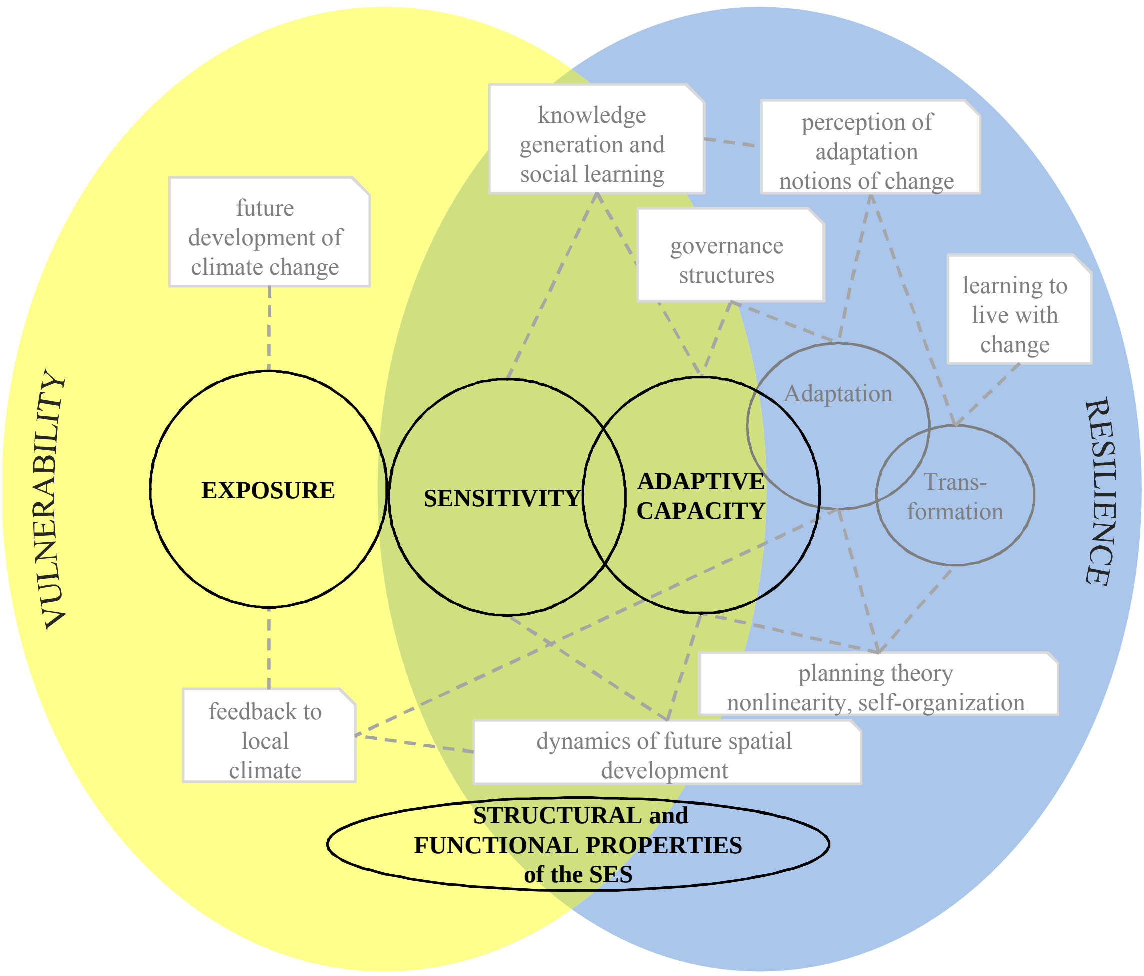

Figure 5: Visualization of the overlap between vulnerability and resilience referring to the interdisciplinary perspective within the project, the single vulnerability elements (exposure, sensitivity, and adaptive capacity) as well as the social-ecological system (SES) approach.

"capacity of actors in a system to influence resilience" (Folke et al., 2010, p. 3), which in principle corresponds with the adaptive capacity definitions in the vulnerability context (cf. Table 2, p. 19). However, the discussion on adaptive capacity in the resilience (thinking) field could also include the notions of persistence, adaptability, and transformation (Folke et al., 2010). Although, these could also be applied in the vulnerability context, a practical application of them in the context of the thesis would be unrealistic. Nevertheless, given the link to planning theory (cf. Figure 5 and Table 3), the resilience concept could be seen as start and end point of the analysis. The start point was the goal of the study to initiate long term, sustainable adaptation of the socio-ecological system driven by the normative setting of resilient thinking. Hence, the analytical framework particularly included system characteristics, describing the structures and processes in the system not only related to ecosystem services, but also different users and knowledge (see also section 5.2.2). Finally, again the more normative setting of resilient thinking guided the discussion of adaptation measures in the context of urban and regional planning. In addition, the implications derived through the discussion of the resilience concept helped framing the analysis of the system to deal with complexity and uncertainty, which are inherent to all three parts of the visualization in Figure 5. The descriptions in Table 3 point at different forms of uncertainty to be acknowledged: 1) the uncertainty about future climate change development and the uncertainty intrinsic to the models describing the effects of climate change, 2) the uncertainty about future development in the region and their implications for urban and regional planning, 3) the uncertainty related to dynamic variables, such as knowledge, and 4) the uncertainty about the social-ecological interdependencies inherent to the system under consideration.

The identification of social-ecological feedbacks is essential to understand interactions in social-ecological systems. Also, Turner et al. (2003a) stress the importance of considering human and environmental conditions as well as their interaction, which were placed in the sensitivity component of their framework. In fact, the resilience perspective has a long history as an approach directed towards understanding the dynamics of social-ecological systems (Folke, 2006). Although further method development is required, one can find examples of empirical evidence in resilience literature, whereas vulnerability assessments still face major challenges in this context (Miller et al., 2010). Thus, the overlap between the concepts (Figure 5) does also include the sensitivity component. Related to the sensitivity component, the description of the social-ecological system by means of a spatial analysis of the ecosystem service supply and demand in the urban region was the focus of this study.

Due to confusion in terms and conceptual challenges, the integration of the resilience and the vulnerability concept is still at an early stage (Miller et al., 2010). A current attempt to integrate them would unnecessarily add confusion to the vocabulary in the development of the framework in this thesis. Consequently, this study focused on the vulnerability assessment, while bearing in mind the achieved progress in the analysis of system dynamics and social-ecological relations in resilience research, especially in method development.

5.4 Key Findings

The interdisciplinary process resulted in an extensive exchange of disciplines, whereby the initial conceptual precision of a social-ecological resilience definition facilitated the uncovering of differences in language and meaning of terms as well as overlaps between disciplines. Climate change impact is a global problem, which manifests differently in different regions. Hence, the exposure was described here as the manifestation of climate change impacts. This climate change manifestation could have, depending on the individual sensitivity, effects on the population as well as on the environment. Adaptive capacity represents not only the main overlap between the vulnerability and the resilience concept, but was shown to be deeply rooted in various disciplines. It was argued that in order to approach adaptive capacity (including the long and short term aspects), it is essential to take governance and knowledge exchange into consideration. For the development of an integrated vulnerability framework, this has important implications for the definition of the social-ecological system, scales to be considered, and the methods for the practical application.

In summary, although the resilience concept was not in the focus of this thesis, the definition of key elements (e.g. essential structural and functional properties of the social-ecological system) and methodological considerations (e.g. scales and the definition of the urban region) were improved through the interdisciplinary perspective. In the end, the focus of this thesis was the characterization of the social-ecological system as a basis for vulnerability analysis, whereby the normative setting of resilient thinking could be seen as a guiding principle.

6 INTEGRATED FRAMEWORK - THE SOCIAL-ECOLOGICAL VULNERABILITY LOOP

One of the main aims of vulnerability research is to inform practitioners to come up with valuable adaptation strategies. Hence, vulnerability variables as well as cause-effect-relationships need to be transparent to communicate the results in a transdisciplinary context. The DPSIR (Driver-Pressure-State-Impact-Response) framework (Figure 6) was developed to organize information, to provide a structure for analyzing indicators, to identify targets, and to evaluate responses (EEA, 1999). Moreover, it is an interdisciplinary tool with an inherent social-ecological approach, as it assumes cause-effect-relationships between social, economic, and ecological systems (EEA, 1999). As such, the DPSIR framework should be integrated taking a social-ecological approach (Kluvánková-Oravská and Chobotová, 2007). In addition, Maxim et al. (2009) proposed the use of the spheres of sustainability (economic, social, political, and environmental). With the characterization of the interactions between spheres, the DPSIR framework enables the discussion of possibilities of action and can help clarifying the contributions of different scientific disciplines (Maxim et al., 2009). Omann et al. (2009) give a good practical example of how the DPSIR approach might be applied in the context of climate change. By identifying the links between climate change, as a major threat to biodiversity, and the underlying socio-economic forces, they formulated the resulting impacts in terms of ecosystem services. Furthermore, Rounsevell et al. (2010) showed how the conflicts and tradeoffs between multiple ecosystem services and service beneficiaries could be analyzed using the DPSIR

"According to this systems analysis view, social and economic developments [**Drivers**] exert **Pressure** on the environment and, as a consequence, the **State** of the environment changes, such as the provision of adequate conditions for health, resources availability and biodiversity. Finally, this leads to **Impacts** on human health, ecosystems and materials that may elicit a societal **Response** that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative action." (EEA, 1999, p.6)

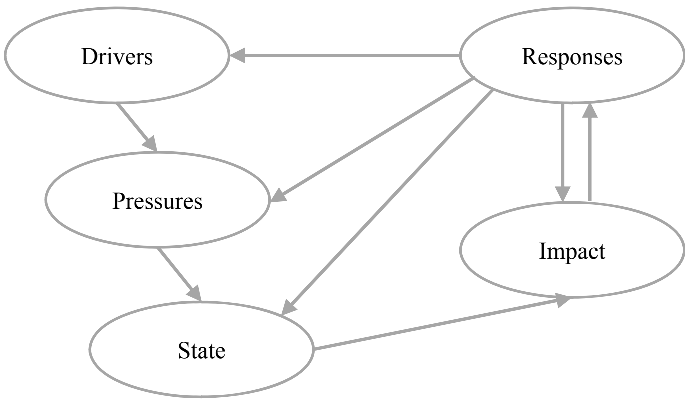

Figure 6: The Driver-Pressure-State-Impact-Response (DPSIR) framework adopted from EEA (1999).

framework. On the one hand, the DPSIR framework provides a good basis for social-ecological system analysis and the integration of the ecosystem service concept. On the other hand, there are many synergies between the DPSIR and the vulnerability vocabulary (Maxim and Spangenberg, 2006) and it is a well-established and accepted form of reporting results to practitioners. Therefore, the DPSIR framework offers a way to gain conceptual clarification, as the literature on vulnerability itself is to some extent inconsistent (cf. Chapter 3). Thus, combining the concepts could contribute to interdisciplinary integration and transdisciplinary communication. Consequently, in order to find a pragmatic way to overcome shortcomings in existing approaches, the social-ecological vulnerability loop integrates the vulnerability concept and the concept of ecosystem services within the DPSIR framework (Beichler et al., 2012).

6.1 The Social-ecological Vulnerability Loop

The social-ecological vulnerability loop (Figure 7) describes the system by untangling the main features of the social system, the ecological system, and their inherent interactions and feedbacks as well as their influence on the social-ecological system as a whole. The use of the DPSIR framework allows for an analysis of the system in a pragmatic and systematic way. To uncover feedbacks and interactions between the elements, the pressure, state, and impact of both, the social and the ecological system are approached separately.

Figure 7 shows the *social system* in red and the *ecological system* in green. Starting on top, the framework understands *climate change* as a global problem outside the system boundary, manifesting itself differently in different regions (cf. Chapter 5.2.1). The manifestation of climate change effects, in vulnerability vocabulary the exposure (cf. Chapter 3), is influenced by the external climate change, but acts within the system boundaries. Hence, the *climate change manifestation* (e.g. drought) was defined as the **driver**, which can take many forms.

The driver has an *effect* on both, the social and the ecological system, which was represented by the **pressure** on the individual systems. Based on the ecosystem service cascade principle (Haines-Young and Potschin, 2010), there are two objects of change: *population* wellbeing as well as *ecosystem* structures and functions (cf. Chapter 4). The pressure relates to limits and thresholds within the social and the ecological system, respectively (Potschin, 2009). Here, the adaptive capacity definition by

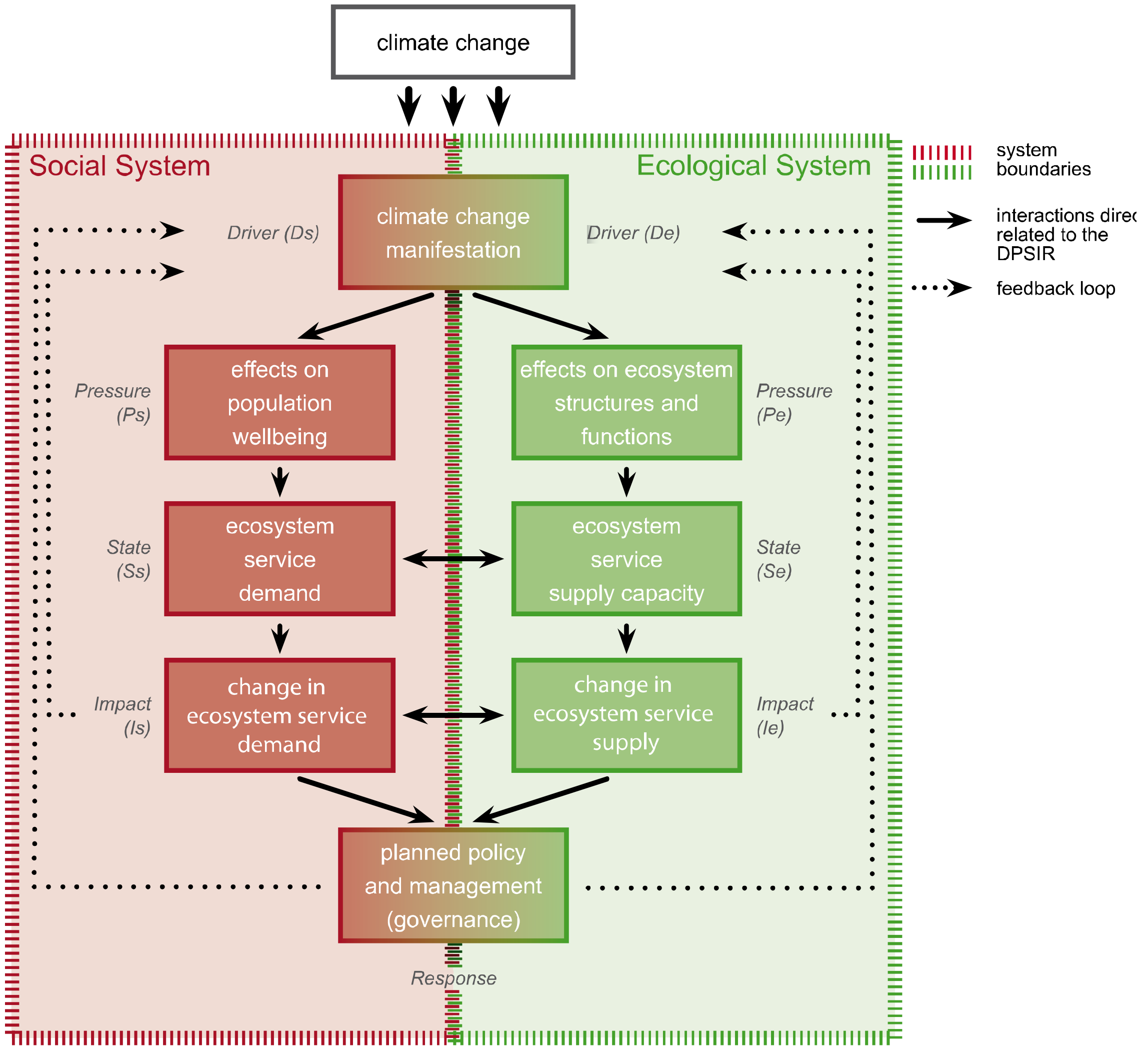

Figure 7: The social-ecological vulnerability loop. Visualization of the social (red) and the ecological (green) system and their interactions.

Brooks et al. (2005) was adopted differentiating between "coping capacity" for short-term and "adaptation strategies" for long-term reactions (cf. Chapter 3). As such, the value of the threshold or limit determines the coping capacity of the system.

The **state** variable embeds the ecosystem service concept (cf. Chapter 4) by means of the supply-demand approach of Burkhard et al. (2012b). This includes a *direct link* (small arrow in Figure 7) between the *ecosystem service supply* of the ecological system and the *ecosystem service demand* of the social system. Thus, a change in the state of the ecological system can also change the social system and vice versa. Equivalent to the framework proposed by Rounsevell et al. (2010), the state variables represent the sensitivity.

The **impact** represents the resulting overall change in the state, which is synonymous to the overall vulnerability (Maxim and Spangenberg, 2006). The impact was described here as the change in ecosystem service demand and supply. There are diverse ecosystem service assessment approaches (cf. Chapter 4). On the regional scale, studies utilizing land use and land cover data offer potential indicators for the quantitative application of the presented framework (cf. Chapter 5.2.3).

Climate adaptation strategies and potential measures involved have to be embedded within a wider decision-making context (cf. Chapter 5.2.2) and are integrated as the intervening variable in the social-ecological vulnerability loop, namely the **response**. In the vulnerability loop, responses and impacts are taken into account as new drivers to create a *feedback loop* (dotted line in Figure 7). This allows a reflection on system dynamics and responses acting on different spatial and temporal scales (Beichler et al., 2012).

6.2 Main Characteristics of the Proposed Framework

In existing applications of the DPSIR framework, the definitions of pressure differ with respect to the object of change (land use, biodiversity), the relationship to change (e.g. long-term climate change), and the character of the pressure (e.g. resources, intensity of actions) (Maxim et al., 2009). Most DPSIR studies consider only anthropogenic factors as drivers, following the EEA definition (EEA, 1999). These could be social or economic developments, thus coming from the social system. Other conceptualizations consider both anthropogenic and natural factors that cause a change in the ecosystem (MEA, 2005), or include also political aspects arising for example from the relationship between stakeholders, leading to an inadequate policy action (Maxim et al., 2009). Climate change is a global problem, in which causes and impacts might be allocated spatially and temporally (cf. Chapter 5.2.1). However, the related drivers are often described rather general, for instance in human activities that cause greenhouse gas emissions (Omann et al., 2009), which hinders a practical application. Although current climate change research states that humans are the main source driving climate change, they are affected at the same time. As such, in the context of climate change, the social system does not essentially need to be the driver, as even climate neutral regions will be affected by climate change impacts. Looking at studies in the vulnerability context, the exposure component is more specific and spatially explicit for the region, e.g. an urban heat island effect (Lissner et al., 2012). The driver causing climate change (e.g. green house gas emissions) is external to the system, but does not influence the system directly, thus does not correspond to hazards or exposure in vulnerability literature. The cause of the manifestation of climate change effects is also external, but it acts directly within the system boundaries (cf. Chapter 5.2.1). It needs to be acknowledged that in this regard the social-ecological vulnerability loop differs significantly from usual DPSIR applications. It is argued here that, in order to evaluate adaptation measures, these components need to be more specific and relevant in order to inform stakeholders.

The definition of pressures differs with respect to the object of change, the relationship to changes (e.g. long term climate change), and the character of the pressure (e.g. resources, intensity of actions), and is described either very general or narrowly (Maxim et al., 2009). Stressing the fact that climate change is a driver for change in the social and the ecological system, it has an effect on both systems. Thresholds are related to the ecological system pressure, defining the point after which ecosystems change to alternative stable states, which might be an irreversible structural and functional change (Potschin, 2009). Thus, the value of the threshold determines the coping capacity of the ecosystem. In contrast, limits are perceived by humans and depend on the context (e.g. cultural, economic). This term is to some extent comparable to the term of acceptability introduced by De Chazal et al. (2008). Depending on what is acceptable, the population will reach limits, after which the wellbeing is compromised.

The state describes the conditions of the system, which can be understood by the concept of dynamic stability (Kluvánková-Oravská and Chobotová, 2007). On the one hand, there is a demand for ecosystem services in the social system. The ecosystem, on the other hand, has a limited supply capacity for ecosystem services (Crossman et al., 2012). The direct link between both systems can be seen in the supply-demand deficit, which might be present even before climate change poses an additional driving force. The ecosystem service supply capacity is related to the land cover, which has direct implications for land use (demand) of the social system. This is however just a theoretical differentiation, as spatial datasets (e.g. corine land cover) mostly do not allow a distinction between land use and land cover (Breuste et al., 2013a). However, both of them have direct implications for the local climate.

The impact can be seen as interaction leading to ecological and social change (Kluvánková-Oravská and Chobotová, 2007). Hence, a change in the state of the ecological system can also change the social system, although the pressure was not relevant to it. After a disturbance, the demand could be the same, but the impact might refer to the change in the supply-demand deficit, which in turn could mean that the demand can no longer be met by the ecological system. Here, the impact refers to the ecosystem supply capacity and the social system demand after a disturbance. The state variables refers to the sensitivity of the ecological and the social system, which is equivalent to the model proposed by Rounsevell et al. (2010). The resulting overall change in the ecosystem service supply and demand as well as their interrelations, represented by the impact, is synonymous to the overall vulnerability.

Responses are usually defined as planned policy and management. As a response, actors can apply different measures acting upon the social or the ecological system. Values, perceptions, processes, and power structures within society influence climate adaptation strategies and potential measures. Thus, they have to be embedded within a wider decision-making context, as such, adaptation is essentially a governance issue (Adger et al., 2009). Adaptations to climate change can be differentiated into autonomous adaptation (reactive) and planned adaptation (proactive) (IPCC, 2007; Omann et al., 2009). Feedbacks make it often hard to separate impacts from drivers (Potschin, 2009). Here, responses but also impacts (that might relate to autonomous adaptations) are taken as new drivers to create a feedback loop.

The framework proposed by Rounsevell et al.(2010) also define drivers and pressures that effect ecosystem service beneficiaries and providers rather similar as presented here, but quantify solely the impacts on ecosystem service provision. In contrast, the DPSIR application of the ecosystem service cascade presented in chapter 4 (Müller and Burkhard, 2012) focuses on the effect of social systems pressures on ecological functions and resulting impacts on ecosystem services and thus human wellbeing. Here, the ecosystem service approach is embedded into the vulnerability framework by combining the ecosystem service cascade (Haines-Young and Potschin, 2010) and the supply-demand approach after Burkhard et al. (2012b). which has a strong influence on the interactions within the systems. Thereby, it is considered that on the one side, the structures and functions of the ecological system are under pressure, leading to a change in ecosystem service supply capacity. On the other side, climate change simultaneously poses a pressure on the population's well-being, leading to a change in ecosystem service demand. Although the approach presented here differs from traditional DPSIR applications, this conceptualization enables the practical application of the ecosystem service cascade in the vulnerability context. Nonetheless, the approach is in line with the theory on social-ecological system as for instance proposed by Ostrom (2009) or in the vulnerability framework of Turner et al. (2003a). Ostrom's framework can be applied using different theories and approaches and supports the process of conceptualization (Schlüter and Hinkel, 2014). As such, it helped to identify important factors to be included: a) The users are represented via the population (amount and social-economic attributes). b) The resource units are ecosystems and their capacity to provide services (including spatial distribution and interaction). c) The governance aspect is integrated via the response element. d) The interactions are an important part within the social-ecological vulnerability loop. In line with the social-ecological framework of Ostrom (2009), not only users and resource units interact (supply-demand), but also the governance responses feed back to the social and the ecological parts of the system. With the feedback loop approach, it was also acknowledged that drivers are formed by interdependent socio-economic and environmental processes (Kluvánková-Oravská and Chobotová, 2007) and could arise from the relationship between stakeholders, leading to inadequate policy action (Maxim et al., 2009).

6.3 Key Findings

The social-ecological vulnerability loop aims at describing the social-ecological system under climate change. By identifying dynamics between the elements of the social and the ecological system and linking responses to the consequences for the whole system, it could serve as a tool to assess the vulnerability. Hereby, the DPSIR framework is a valuable tool to organize the vulnerability elements, structure the steps of analysis, and think about potential indicators. Herein, the implications of the previous three chapters on vulnerability theory, ecosystem services, and the interdisciplinary process were brought together. Hence, the framework refers to the basic vulnerability definition (Chapter 3), the concept of ecosystem service supply and demand (Chapter 4) as well as the interdisciplinary implications considering the scales of analysis as well as notions of climate change impact and adaptive capacity (Chapter 5). The results contribute to answering the questions of this thesis, as to which theoretical frameworks can be used and how the different concepts can be integrated.

In the following chapters, the described assessment approaches of the concepts will be taken up, showing how the social-ecological vulnerability approach can be applied, identifying the dynamics within the social-ecological system, and exploring potential climate change adaptation measures.

7 CASE STUDY AND METHODS

7.1 The Urban Region of Rostock (Germany)

The urban region of Rostock (Germany) is situated on the Baltic Sea coast. Coastal cities are particularly interesting case studies in the context of climate change research. There is a potentially high exposure to different extreme events (e.g. floods and heavy rain) and gradually changing variables (e.g. sea level rise) (IPCC, 2007). Due to the worldwide high population density along the coasts, coastal ecosystems are greatly influenced and highly altered and hence susceptible to disturbances (Adger et al., 2005). As such, the characteristics of cities, such as the high population density, multiple land use conflicts (e.g. the contrast between urbanization and valuable coastal ecosystems), and the specific climatic conditions (e.g. the urban heat island effect) need to be considered in the context of climate change adaptation.

The urban region under consideration comprises a medium-sized city (199,380 inhabitants in 2009, Statistische Ämter des Bundes und der Länder (accessed 2013)) as well as the surrounding rural communities (Figure 8a). The city comprises an area of 181 km^2, whereas the overall urban region, which also includes all adjacent

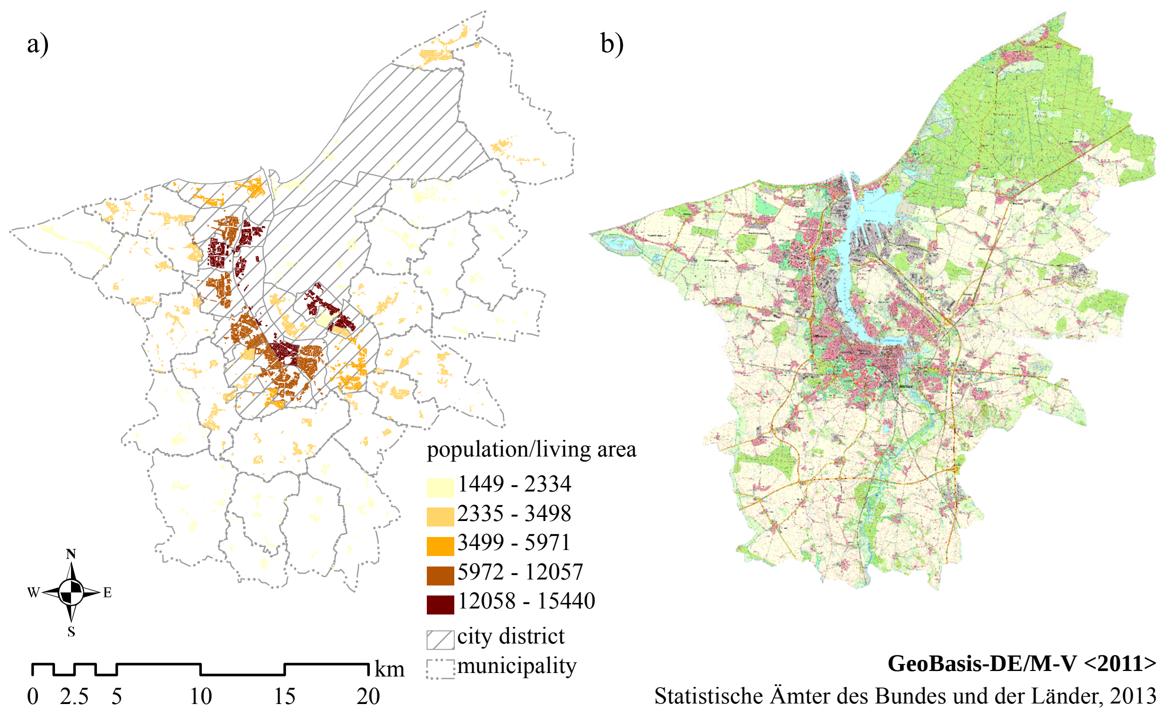

Figure 8: The urban region of Rostock. a) Population per km^2 living area b) Topographical map.

municipalities, covers an area of about 553 km^2 with an overall population of 245,981 in 2009 (Statistische Ämter des Bundes und der Länder (accessed 2013)).

Rostock is the largest city in Mecklenburg-West Pomerania. In recent decades, the population has been growing, due to the area's favourable conditions for families and elderly people. The topographical map in Figure 8b gives an overview on the case study region. The key economic sectors are the port, the associated maritime economy, and tourism. In addition, Rostock is attractive as a university location and offers culture, entertainment, and job opportunities. The urban region provides several possibilities for recreation, with the most popular being long stretches of beach. From an ecological perspective, the area is of interest because of its valuable coastal ecosystems, the Warnow, and the Rostocker Heide. The river Warnow spans from the south of the study area to the very north, where it flows into the sea (cf. Figure 8b). The Rostocker Heide is an extensive forest area to the southeast of the urban region covering about 60 km^2.

The spatial analysis was related to two main spatial scales. First, the administrative borders, for which statistical data on the population was available, were used. Here, 21 city districts and 24 municipalities were distinguished (Figure 9). Second, the land use / land cover information was based on the digital topographical map (DTK25,

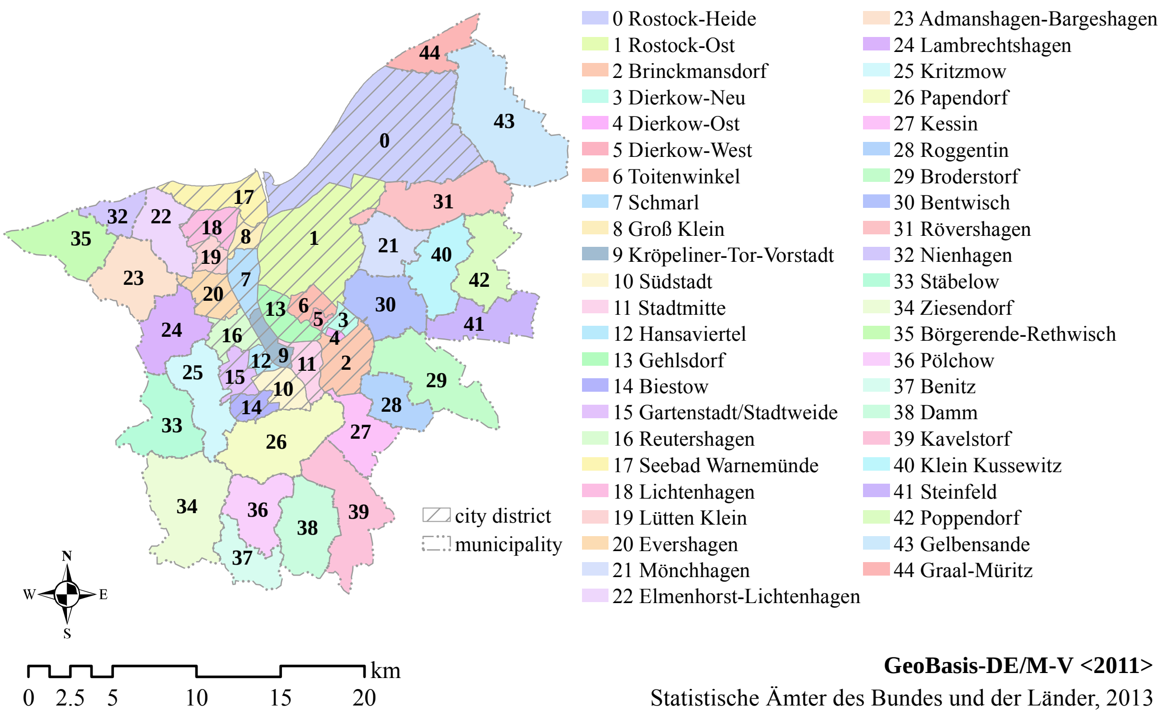

Figure 9: Case study area division into city districts and rural municipalities.

©GeoBasis-DE/M-V (2011), cf. Figure 8b). For a better representation and comparability of results particularly of the ecosystem service demand, the population data from the individual districts/municipalities was transferred to the available living area in the districts/municipalities (as displayed in Figure 8a).

7.2 Inter- and transdisciplinary Knowledge Base

The urban region of Rostock was a prominent case study within the research project plan B:altic. This enabled to draw from a broad interdisciplinary knowledge base considering e.g. governance aspects or climate change effects (cf. Chapter 5). Moreover, in the context of the project, transdisciplinary results were established throughout a scenario planning process (Hagemeier-Klose et al., 2014, 2013). Three workshops facilitated stakeholder participation and enabled the integration of specific local knowledge from different perspectives. Stakeholders (from administration, politics economy, science, and civil society) discussed key factors for future spatial development as well as relationships between these factors and potential climate change impacts (Hagemeier-Klose et al., 2014, 2013).

Throughout the process, detailed information on the case study area was derived: 1) material and information obtained from the stakeholders; 2) the results of the process itself, which refer to adaptation measures and strategies discussed by the participants of the workshops (Hagemeier-Klose et al., 2012). Some of these have been included in the official adaptation plan of the city of Rostock (Hansestadt Rostock, 2013); 3) the observations made during the process including conflicting statements that were mentioned. This information was used in this thesis establishing a reference to the ongoing dialogue in the urban region of Rostock. Here, the exchange of knowledge was reflected to approach adaptive capacity.

7.3 Participatory Assessment in the Urban Region of Rostock

The quantitative application of the framework was based on a participatory mapping approach acquiring empirical data on perceived vulnerability and CES. A detailed description of the approach is given in Beichler (2015)[1], which will be summarized in the following. In order to assure a reasonable time frame for the assessment, this thesis focuses on CES, which were identified to be most suitable in this context as elaborated

[1] Vorabveröffentlichung der Dissertation see page 1

in Chapter 4.3. The list of CES to be assessed was compiled by comparing different classifications systems (Burkhard et al., 2010a; Crossman et al., 2013; de Groot et al., 2002; Hermann et al., 2011; MEA, 2005) as well as results and method discussions of case studies using participatory approaches (Brown and Reed, 2012; Brown et al., 2012; Bryan et al., 2010; Fagerholm et al., 2012; Koschke et al., 2012; Niemelä et al., 2010; Raymond et al., 2009; Sherrouse et al., 2011). The final list of CES included aesthetics and inspiration (aest), spiritual and religious (spirit), cultural heritage and identity (cult), recreation (recr), knowledge and education (edu), and natural heritage and intrinsic value of biodiversity (nat). The 36 participants filled in an extensive survey (adopted from Brown et al., 2012; Fagerholm et al., 2012)(Appendix A, p. 119ff). The participatory mapping was administered in six groups (as described in Hagemeier-Klose et al., 2014) using printed topographical maps (adopted from Fagerholm and Käyhkö, 2009; Fagerholm et al., 2012). Referring to the CES by means of easily accessible questions (Plieninger et al., 2013), the participants delineated the CES on the map and indicated a quality value from 1 (very low quality) to 5 (very high quality) (cf. Figure 10). The mapping of the individual CES was followed by a ranking of the importance of the service for personal wellbeing and the satisfaction with supply in the urban region Rostock (cf. Appendix A, p. 119ff). For the participatory mapping of perceived vulnerability, it was referred to areas that would be avoided during or after the extreme events heat wave, extreme precipitation, or drought (Beichler, 2015; Hagemeier-Klose et al., 2014).

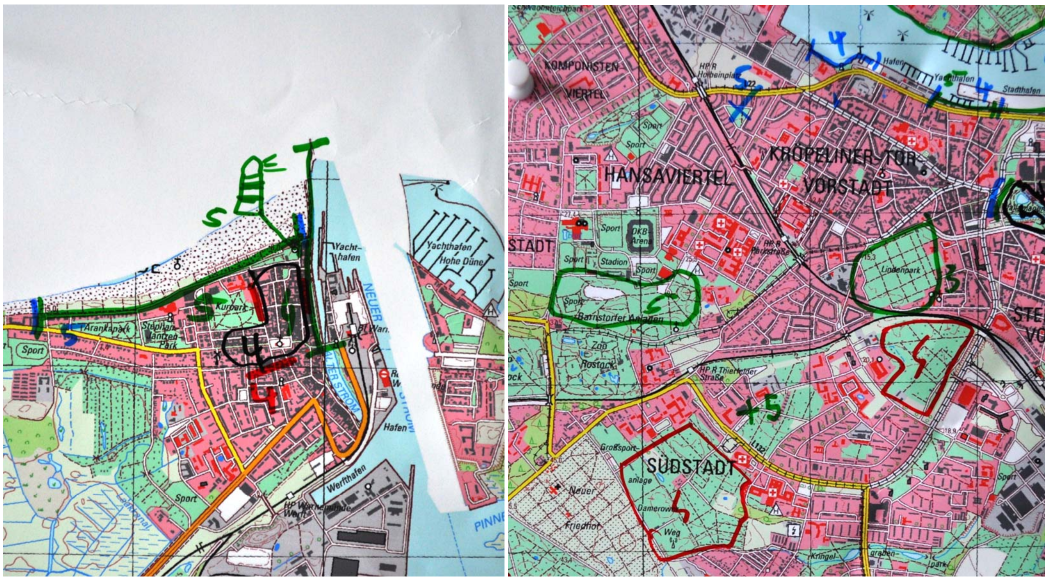

Figure 10: Example of the participatory mapping

7.4 Spatial Analysis

The empirical data derived through the participatory mapping was analyzed in several steps. First, the individual CES areas mapped by the participants were correlated to land use classes (database cf. Section 7.1) distinguishing areas with high (5-4) and medium (3-2) values. In addition, the spatial overlaps between the different CES were calculated. Second, the mapped data (individual areas in the raw data) and the clustered data (dissolved according to the CES classes) were compared to reflect upon the participatory method used. Moreover, the clustered CES maps served as a basis to describe the CES in the urban region. In the subsequent steps (cf. Figure 11), the

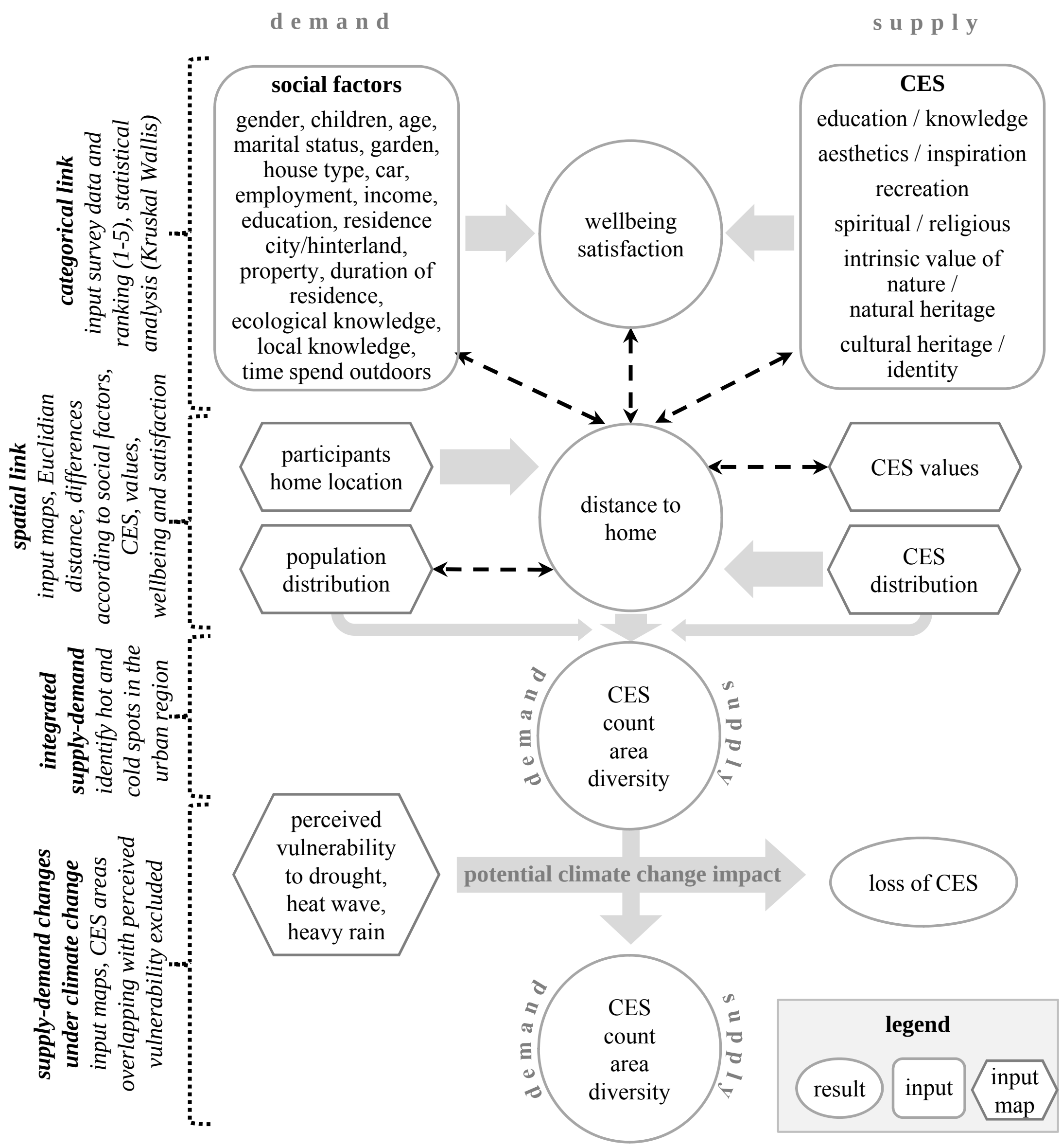

Figure 11: Description of the spatial analysis methods conducted. Figure adopted from Beichler (2015)

categorical link between recorded social factors and CES as well as the spatial link between supply and demand were analyzed as elaborated in detail in Beichler (2015). The categorical link referred to relations between the ranking of wellbeing and satisfaction, the 16 social factors (included in the survey), and the different CES. The spatial link was analyzed based on the distance to home (DTH), which was reflected considering various factors (cf. dashed arrows in Figure 11). The integrated supply-demand map was derived through a neighborhood analysis using the critical distances identified for the individual CES. To characterize the urban region, the results were accumulated calculating the total supply area, the number of areas, and the diversity/number of different CES. To illustrate potential changes under climate change the neighborhood analysis was repeated excluding areas of perceived vulnerability.

8 APPROACHING ADAPTIVE CAPACITY

As pointed out in Chapter 3, for determining adaptive capacity, knowledge is a decisive factor, which is highly dynamic. In order to gain a comprehensive picture of climate change adaptation with a special focus on adaptive capacity, interdisciplinary and transdisciplinary knowledge must be assessed and processed, integrating different kinds of knowledge (Hagemeier-Klose et al., 2014). The different stages of interdisciplinary and transdisciplinary work were structured by organizing and grouping the different forms of knowledge and the interfaces of knowledge exchange in the knowledge loop.

The dynamic knowledge loop (Figure 12) was developed to explore inter- and transdisciplinary knowledge generation; mechanisms of knowledge exchange; the integration of different forms of knowledge, such as scientific, local, and practical knowledge; and associated learning processes as described in detail in Hagemeier-Klose et al. (2014)[1]. The *knowledge of adaptation* (blue box Figure 12) refers to the scientific knowledge base. The first part of the loop represents the *science–science knowledge exchange* that influences the *knowledge of adaptation*. The comprehensive social-ecological system approach includes undertaking research in different disciplines (cf. Chapter 5). Due to the exchange between disciplines, this feedback loop triggers the *adaptation of knowledge* (red box in Figure 12). The second loop refers to p*ractical* local knowledge transferred to *scientists* at this stage. This included data that was shared and transdisciplinary methods to acquire empirical data. The third knowledge loop refers to the two-sided *science–practice* exchange of knowledge. Here, the transdisciplinary scenario process was examined. The combination of the different steps (in Figure 12) showed the interplay between the *knowledge of adaptation* and the *adaptation of knowledge* to approach the adaptive capacity of the overall system. A detailed discussion of the application of the knowledge loop was given in Hagemeier-Klose et al. (2014), which is summarized in the following.

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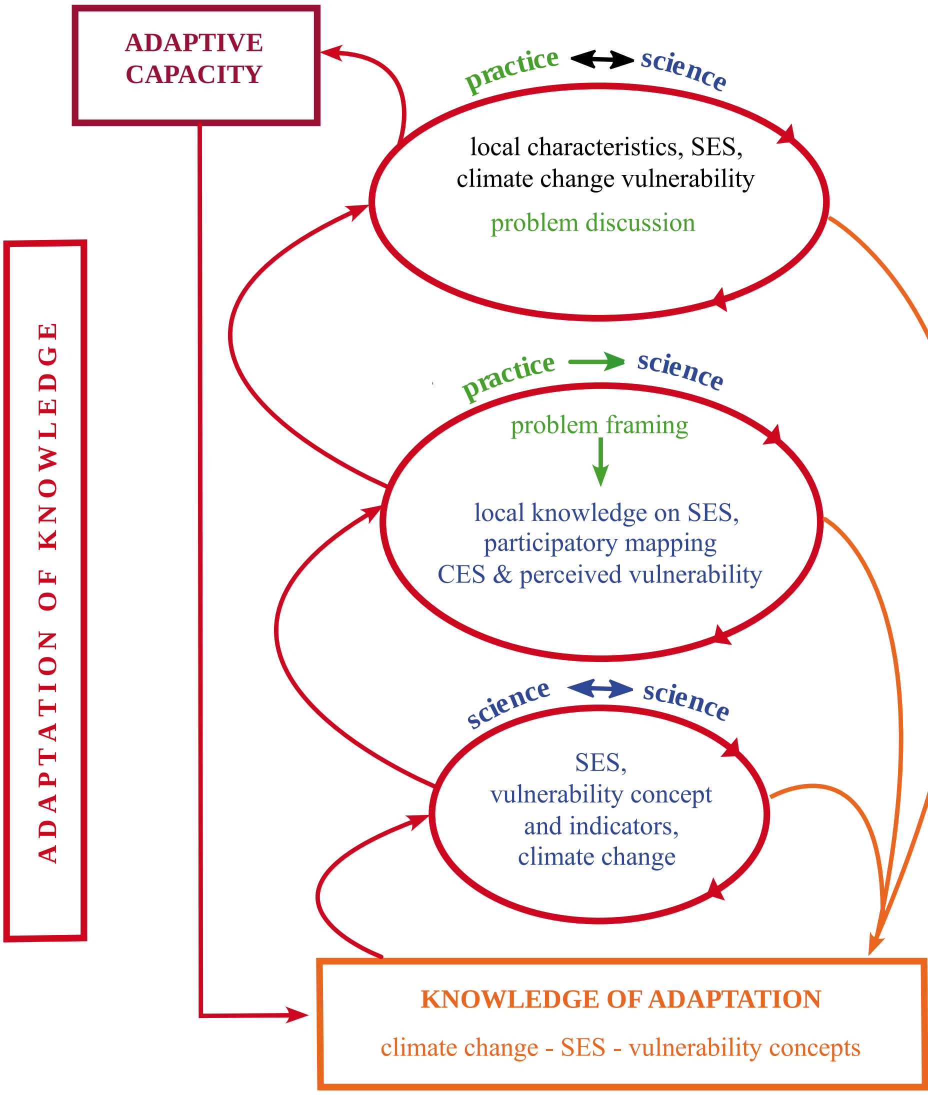

Figure 12: The dynamic knowledge loop adopted from Hagemeier-Klose et al. (2014). The application in the context of vulnerability research in social-ecological systems (SES) illustrates the interplay between the knowledge of adaptation (orange) and the adaptation of knowledge (red) influencing the adaptive capacity (dark red). Blue refers to scientific implications and green indicates implications for practitioners involved in the process.

8.1 First Knowledge Loop Science ←→ Science

The science-science loop (Figure 12) in the context of this thesis was related to the reflection of literature on vulnerability theory and indicators (Chapter 3) and the social-ecological system research perspective, particularly ecosystem services (Chapter 4) as well as the interdisciplinary process (Chapter 5). These conceptual considerations helped to understand the characteristics of a social-ecological system under climate change and to integrate them into vulnerability analysis in order to uncover problems concerning adaptive capacity measurements. In the science-science loop, the knowledge of adaptation was adapted by combining information about the social-ecological system, its constituents, and the interconnections and feedback that determine the vulnerability of the system to climate change impacts. As a result, these aspects were integrated in the social-ecological vulnerability loop (Chapter 6).

8.2 Second Knowledge Loop Practice → Science

The one-way practice science loop describes the step of acquiring local knowledge, which was integrated in scientific research. This referred to the determination of factors relevant in the specific case study region (cf. Chapter 7.2.). Furthermore, a knowledge transfer from practice to science took place through the participatory mapping of CES and perceived vulnerability (cf. Chapter 7.3). The participatory mapping enabled to bring local knowledge into the spatial context revealing a considerable amount of valuable data. As such, the adaptation of knowledge in scientific terms included local information about the characteristics of the social-ecological system considering e.g. multifunctional hotspots (cf. Chapter 9.1). Moreover, it was revealed, how the stakeholders perceived the climate conditions in the urban region (cf. Chapter 9.2). Providing input for analysis, practitioners undertook problem framing by dealing with the potential impacts of climate change.

8.3 Third Knowledge Loop Science ←→ Practice

In the third knowledge loop, the adaptation of knowledge is regarded as more far-reaching than in the first and second loop. This is because cooperation between scientists and practitioners led to knowledge exchange and joint knowledge generation about the local characteristics of the social-ecological system, climate change impacts, and vulnerability. In this regard, many participants stated that they have never consciously thought about the spatial distribution of regional characteristics or how climate change could affect them, and as such showed a great interest in the scientific perspective. Moreover, the group environment positively influenced the mapping process through the exchange of experiences among participants.

In the scenario planning process, 18 different factors for future development (climate change impacts, social, economic, political, and environmental factors) were prepared and evaluated considering spatial relevance and dynamic character (e.g. changing rapidly) in the case study region in order to reveal potential impacts on spatial development in the region. For some factors, opinions about their dynamic character and spatial relevance differed within groups, leading to an exchange of knowledge between scientists, practitioners, and disciplines (or sectors). For example, opposing to the scientists perspective, during the discussion of key factors, the practitioners considered only extreme weather events to be of very high importance and the other climate change factors were thought to be of medium relevance. The practitioners identified the demographic structure, transport infrastructure, and the development and quality of free areas to be highly relevant for the future. Moreover, the evaluation revealed the high importance of dealing with water resources in the region, which was initially considered to have little relevance by scientists (Hagemeier-Klose et al., 2014).

Among the participants, problem discussion took place considering the key factors for future spatial development and the various interdependencies among these factors and climate change. Thus, knowledge on the social-ecological system was generated across sectors. The practitioners were confronted with the complexity and uncertainty related to climate change impacts and links to other factors (Hagemeier-Klose et al., 2014, 2013). The different weighting of scientists and practitioners indicated a potential mismatch between the knowledge generated by science and the knowledge demanded by practitioners. Scientists adapted their knowledge by learning more about the social-ecological system, about the judgments of the local practitioners, the anticipated impacts of climate change, and about the practitioner's demands for vulnerability assessment.

8.4 Key Findings

Summarizing, knowledge as a decisive variable of adaptive capacity is highly dynamic. Here, the different dimensions of adaptive capacity of a social-ecological system were approached interdisciplinarily from the knowledge of adaptation in terms of vulnerability mapping to the transdisciplinary knowledge generation within the scenario planning process. Adequate knowledge of adaptation is required to formulate and implement an adaptation framework or strategy considering climate change, the interconnections within the social-ecological system, and possible future developments of very different aspects of spatial development. Through the inter- and transdisciplinary research process, adaptation of knowledge took place (Hagemeier-Klose et al., 2014), which led to the creation of a complex picture of the social-ecological system under climate change enhancing the overall adaptive capacity.

9 CHARACTERIZATION OF THE URBAN REGION

This chapter gives an overview on the empirical findings of the thesis. In this regard, the results concerning the spatial distribution of CES and perceived vulnerability, the exploration of the categorical, and the spatial link between supply and demand, as well as the integrated supply-demand analysis and the final vulnerability analysis are presented. Whereas an in depth discussion of the results and the applied methods is provided in Chapter 10.

The results of the participatory mapping in the urban region of Rostock have in part been described in Beichler (2015) and Hagemeier-Klose et al. (2014). The raw data is listed in Table 4 and Table 5, and illustrated in Figure 13 including the CES aesthetics and inspiration (aest), spiritual and religious (spirit), cultural heritage and identity (cult), recreation (recr), knowledge and education (edu), and natural heritage and intrinsic value of biodiversity (nat). For the CES, 954 entries were delineated by the participants, whereby aest accounted for the highest and spirit for the lowest number (Table 4). For the perceived vulnerability 136 entries were mapped (grey striped areas in Figure 13), whereby extreme precipitation accounted for the highest number and largest area of entries delineated (Table 5).

Table 4: Results of the participatory mapping of cultural ecosystem services showing raw data and the data with overlap correction.

Cultural ecosystem services	raw data		overlap corrected	
	area km^2	number	area km^2	number
spiritual and religious (spirit)	11	67	8	35
knowledge and education (edu)	49	124	19	45
cultural heritage and identity (cult)	566	172	136	21
aesthetics and inspiration (aest)	663	229	182	29
recreation (recr)	957	214	178	26
natural heritage and intrinsic value of biodiversity (nat)	1247	148	186	26

Table 5: Results of the participatory mapping of perceived vulnerability to climate change showing raw data and the data with overlap correction.

perceived vulnerability	raw data		overlap corrected	
	area km^2	number	area km^2	number
drought	255	12	106	7
heat wave	217	61	57	8
extreme precipitation	428	63	113	14

As illustrated in Figure 13, the entries were so dense that the individual CES and associated colors obscured each other, indicating that the entries of the different participants coincided. For analysis, the areas delineated by the individual participants were clustered by theme (dissolved according to the CES classes) aggregating all overlapping areas that belong to the same CES. Comparing the final map with clearly assigned areas for all individual CES (Figure 14) with the raw data (Figure 13), the total area was considerably reduced. For example for nat, the raw data, which accounted for 1247 km^2, was reduced to 186 km^2. This holds true for almost all CES (Table 4) and the areas of perceived vulnerability (Table 5) indicating that the entries were frequently repeated in the same location and thus verified by different participants. Only for spirit, very few entries were in the same location.

In the following, first, the spatial distribution of CES is described analyzing the relation to land use classes and the overlap of the individual CES. Second, the results on perceived vulnerability are presented including the overlap with CES in the urban region.

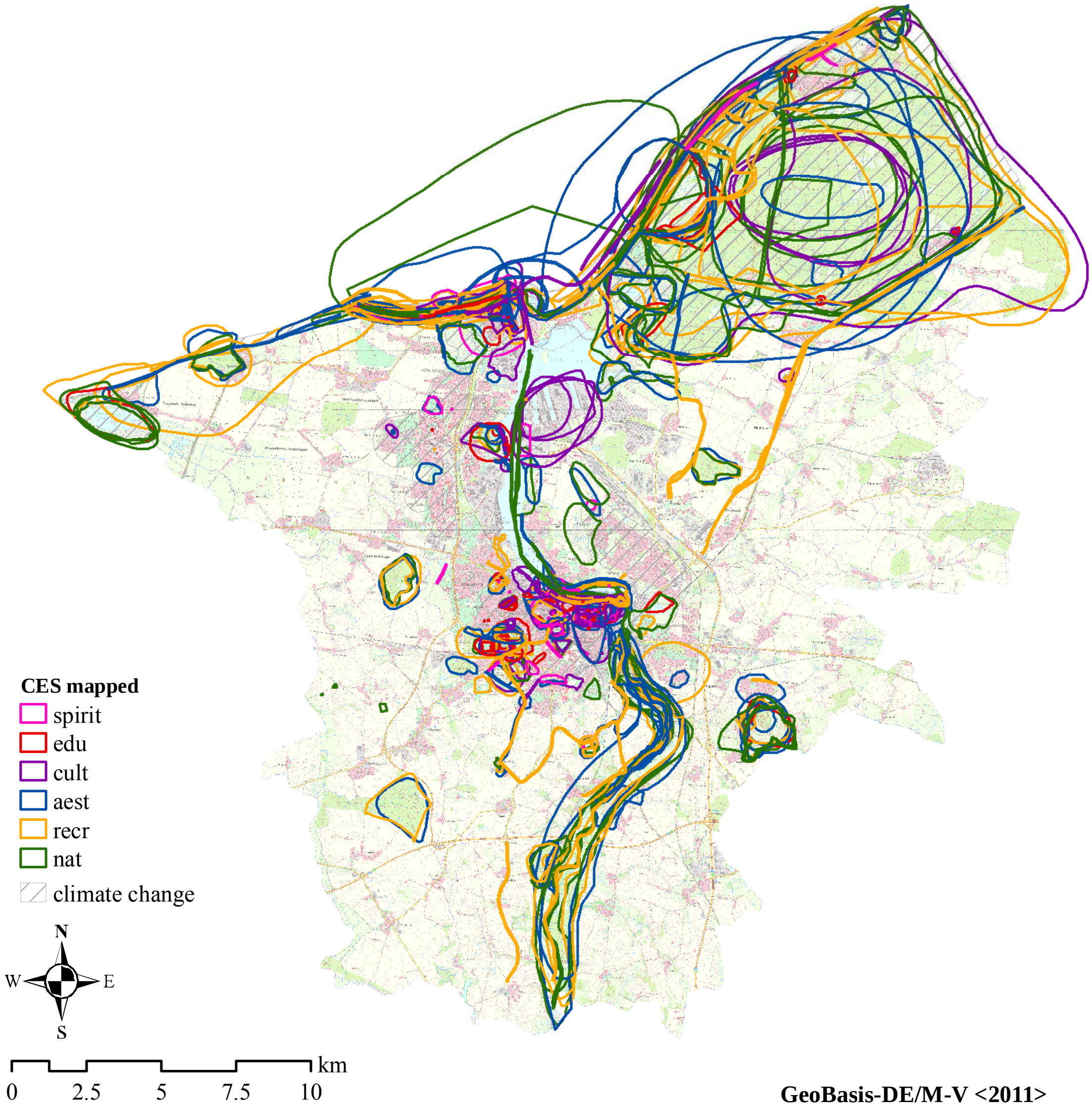

Figure 13: Map showing the individual entries of the participatory mapping of the cultural ecosystem services (CES) aesthetics and inspiration (aest), spiritual and religious (spirit), cultural heritage and identity (cult), recreation (recr), knowledge and education (edu), and natural heritage and intrinsic value of biodiversity (nat) in the urban region of Rostock. The results from the participatory mapping of the perceived vulnerability are indicated by the striped area. The topographical map is depicted in the background.

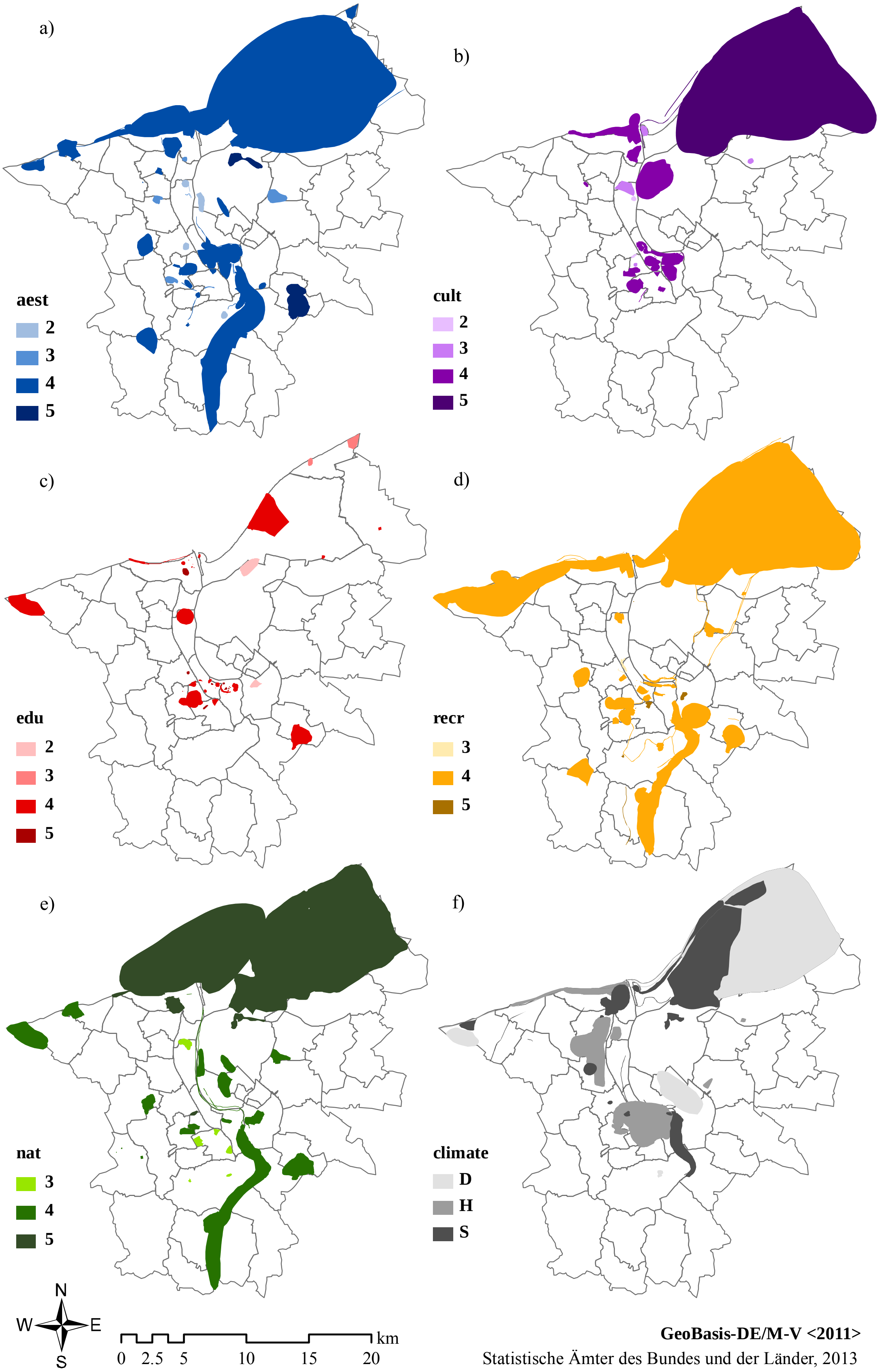

Figure 14: Resulting cultural ecosystem service areas including quality ranks (5 very high – 1 very low) for a) aesthetics and inspiration (aest), b) cultural heritage and identity (cult), c) knowledge and education (edu), d) recreation (recr), e) natural heritage and intrinsic value of biodiversity (nat). Areas of perceived vulnerability to drought (D), heat wave (H) and extreme precipitation (S). (modified Source: Beichler, 2015)

9.1 Supply of Cultural Ecosystem Services

The results of the land use classes (cf. Figure 8b, p. 58) that related to the different CES areas (Figure 13) are visualized in Figure 15. These are complemented here by the evaluation of the quality criteria for the CES (cf. Chapter 7.3, Figure 10, p. 61). For high value areas of the CES nat, cult, recr, and aest, a similar picture was revealed (Figure 15). For all of them, a high importance of forest was found and they were to some extent related to the land use class pasture. In addition, for the CES nat and aest, a high share of Baltic Sea was found. For nat, cult, and recr, areas valued high differed considerably from areas values medium with regard to the related set of land use classes.

For cult, the biggest difference between high and medium value areas was found. In this CES class, medium value areas related mainly to the land use classes industrial and inland water. In the description of the quality criteria for cult, the participants referred to

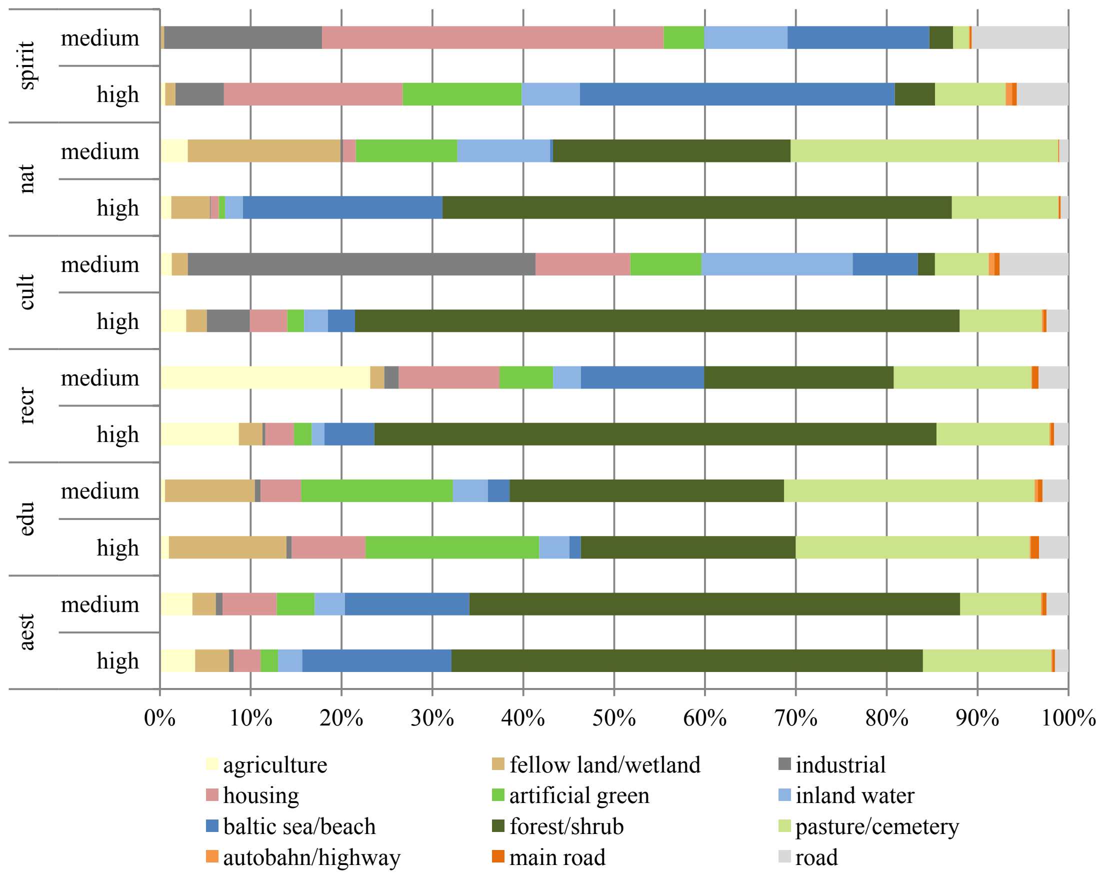

Figure 15: Visualization of the share of land use classes (see legend) related to the individual CES areas. Areas valued high (5-4) and medium (3-2) are distinguished.

the history and cultural identity of Rostock characterized by the maritime environment. This was mainly related to natural places at the coastline (particularly Warnemünde) on the one hand, and to the harbor areas and the river Warnow on the other hand.

For the medium value areas of recr, a mixture of the land use classes pasture, forest, Baltic Sea, agriculture, and to some extent housing and artificial green was found. In the descriptions of recr and aest, the participants referred mainly to nature experiences including silence, view, and landscape character. Here, the coast and the Rostocker Heide were frequently mentioned. For recr the participants also referred to outdoor activities (cycling, walking, etc.) emphasizing possibilities for local recreation. Medium value areas of nat were related to pasture, forest, inland water, artificial green, and wetlands. In the context of nat, the participants referred to naturalness, pristine areas, and specific ecosystems. The mix of land use for medium value nat areas was comparable to the findings for high and medium value areas of edu. Yet, for edu, a higher share of artificial green was observed. Concerning edu, the participants mentioned experiences of nature and specific educational opportunities (e.g. zoo and botanical garden) most frequently, but also education on history and culture related to the landscape, architecture or specific facilities.

The class spirit included a high share of housing area. In addition, areas with high values included a high share of Baltic Sea (Figure 15). The evaluation of the qualitative description revealed that spirit related to very personal and intimate experiences of individual participants as well as sacred buildings. That complemented the finding that spirit areas were not verified (Table 4, p. 68). Consequently, spirit was excluded from subsequent analysis.

The **pairwise intersection** between the CES areas is depicted in Figure 16 showing the percentage of area of other CES within the total area of the individual CES. In this regard, it has to be kept in mind that the smaller share of edu (7-9% of the area of the other CES) represented a high overlap, as the total area of edu was much smaller (i.e. ca. 10% of the total area of nat, Table 4). Interestingly, although the total area of edu and cult was comparable, these CES classes overlapped only to a very small extent. In general, a very high overlap of all CES was found. 76% of the area of aest and 84% of the area of edu included nat. For recr 74% and for nat 75% of the area accounted also for aest. For the areas of cult, 85% were also related to recr. Due to the very high overlap of all CES, one might be led to assume that the participants were not able to

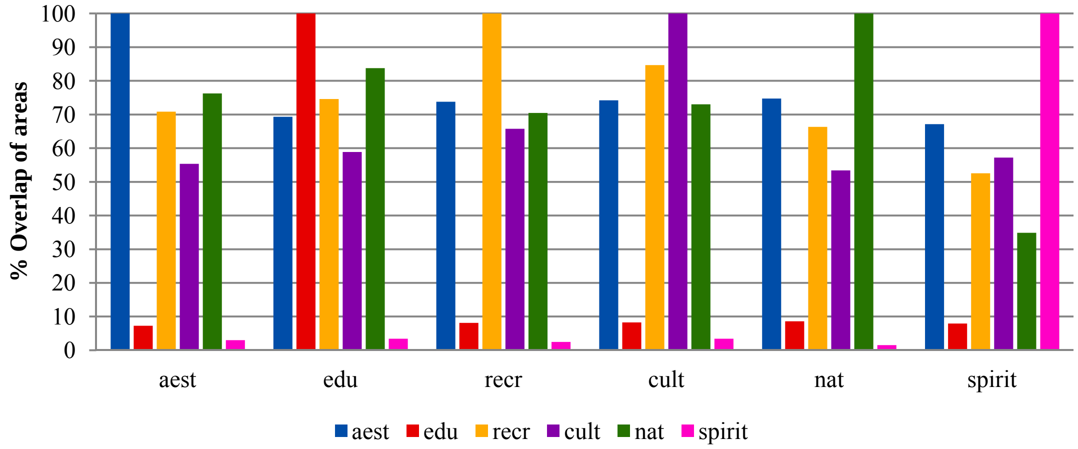

Figure 16: Overlap between the individual cultural ecosystem services aesthetics and inspiration (aest), knowledge and education (edu), recreation (recr), cultural heritage and identity (cult), natural heritage and intrinsic value of biodiversity (nat), and spiritual and religious (spirit).

distinguish between the individual CES. This is contradicted by the different descriptions with regard to quality criteria's (see above) and the differences in the spatial characteristics of the individual CES e.g. comparing the rather large areas for recr (Figure 14d) and the more distinct smaller areas for cult (Figure 14d).

The maps of the CES (Figure 13 and Figure 14) enabled a description of the **local characteristics** of the case study area. Multifunctional hotspots with different key uses could be identified (cf. Beichler, 2015). At the Baltic Sea coast, three main areas could be distinguished. First, the "Rostocker Heide" a large forested area in the northeast, which has a high nature value for the overall region. Second, west of the river is "Warnemünde", a tourist hotspot area with sandy beach and many recreational facilities. Third, in the more western part of the coastline, an area includes the nature reserve area "Stolteraa". Here, the coast is steeper and more activities close to nature are available (e.g. hiking paths). In the middle of the map, many small areas with mostly medium quality could be found, which are related to all kinds of different CES in the city centre. Moreover, at the riverside in the south, overlapping areas of nat, aest, and recr could be found. In the mid-north, the importance of the harbor for cult was highlighted. For edu, rather small and more distinct areas could be found, that on the one hand relate to specific places in the city. On the other hand, they relate to nature reserves in the rural areas (e.g. far west), where edu and nat overlapped.

9.2 Perceived Vulnerability

The subsumed area of all areas associated with drought, extreme heat, and extreme precipitation accounted for 146 km^2 (cf. striped areas in Figure 13, Figure 14f). Hotspots of perceived vulnerability to extreme heat could be found in the city and at the coastline, particularly the beach area. For drought the participants identified mostly larger areas in rural locations. For extreme precipitation, the participants delineated several areas in the city and the hinterland, which highlight the same hotspots as for the CES namely Warnemünde, the Rostocker Heide, parts of the riverside, and smaller specific areas in the city centre. The overlay with the CES map revealed that 57-77% of the CES areas are avoided during or shortly after extreme events (Table 6). In addition, the number of CES areas was reduced, e.g. for edu from 45 (Table 5, p. 69) to 11 (Table 6).

Table 6: Areal statistics of the overlap between the cultural ecosystem services and perceived vulnerability (CC).

cultural ecosystem services	excluding CC		CC overlap
	area km^2	number	%
knowledge and education (edu)	5	11	73
cultural heritage and identity (cult)	31	14	77
aesthetics and inspiration (aest)	76	25	58
recreation (recr)	70	16	60
natural heritage and intrinsic value of biodiversity (nat)	80	22	57

9.3 Exploring the Categorical Link between Supply and Demand

In general, the importance of the individual CES for wellbeing and the satisfaction with the supply in the urban region (Appendix A: Questionnaire participatory mapping, p. 119) were ranked rather high by the participants (Figure 17a and b; cf. Beichler, 2015). For nat and recr (Figure 17a), the mean values for importance for wellbeing (4.39; 4.64) were significantly higher ($p<0.0001$) compared to the other CES (aest 3.97;

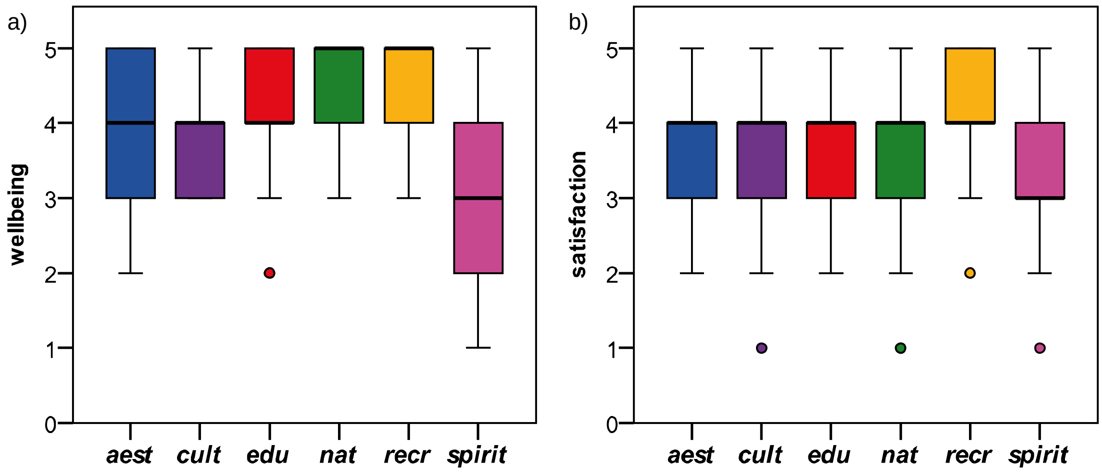

Figure 17: Ranking for the cultural ecosystem services aesthetics and inspiration (aest), cultural heritage and identity (cult), knowledge and education (edu), natural heritage and intrinsic value of biodiversity (nat), recreation (recr), and spiritual and religious (spirit) according to a) the importance for wellbeing and b) the satisfaction with supply. Source: Beichler, 2015.

cult 3.91; edu 4.03), whereas the value for spirit (3.00) was significantly lower. The mean for the satisfaction with supply (Figure 17b) was significantly higher for recr (4.27; $p<0.001$) compared to the other CES. No direct relation between the number and area of services delineated and the satisfaction or the importance for wellbeing was found.

To test the influence of the social factors (included in the survey) with regard to the importance for wellbeing and the satisfaction with supply of the individual CES, the 16 factors were grouped to ensure statistical testability ($n\geq8$). The comparison of the social factors was visualized using grouped boxplots for the importance for wellbeing (Figure 18) and the satisfaction with supply (Figure 17 and Appendix B, p. 126). No general tendency for all CES regarding the relation between social factors and the importance for wellbeing and satisfaction with supply was found. Considering the individual CES and the importance for wellbeing, edu was ranked significantly lower ($p<0.01$), if the income was more than 3000 € per month (Figure 18p). For wellbeing, trends ($p<0.05$) were found for cult (Figure 18a-residence, l-ecological knowledge, g-house type, j-car owner), aest (Figure 18f-marital status), and spirit (Figure 18n-education). Considering the satisfaction with supply, older people (>50 years) ranked nat significantly higher than younger (<35 years) and cult showed a similar trend (Figure 19c). Furthermore, trends were found for nat regarding the duration of residence and females ranked the satisfaction higher for edu and recr (Figure 17a and b). In the context of ecosystem services, one could have expected a difference with regard to the living situation (house type, access to garden, residential property) between people with children and without children, considering car owners, and according to ecological knowledge or time spent outdoors. Here, no significant differences were found (cf. Figure 18 and Appendix B) indicating that no relevant social factors could be found that influenced the spatial distribution of CES demand.

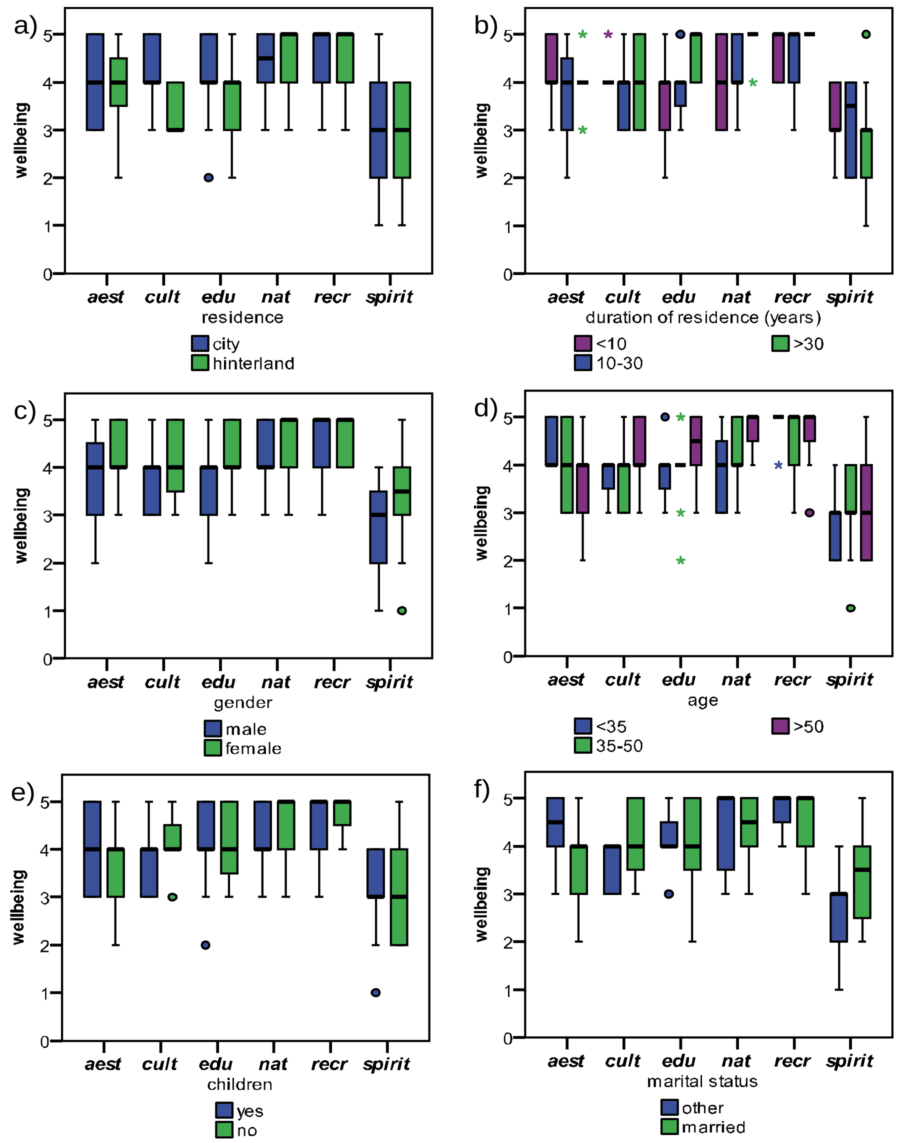

Figure 18: Comparison of importance for wellbeing (1, not important – 5, very important) for the individual cultural ecosystem services aesthetics and inspiration (aest), cultural heritage and identity (cult), knowledge and education (edu), natural heritage and intrinsic value of biodiversity (nat), recreation (recr), and spiritual and religious (spirit) with regard to grouped social factors a) - p). Source: Beichler, 2015

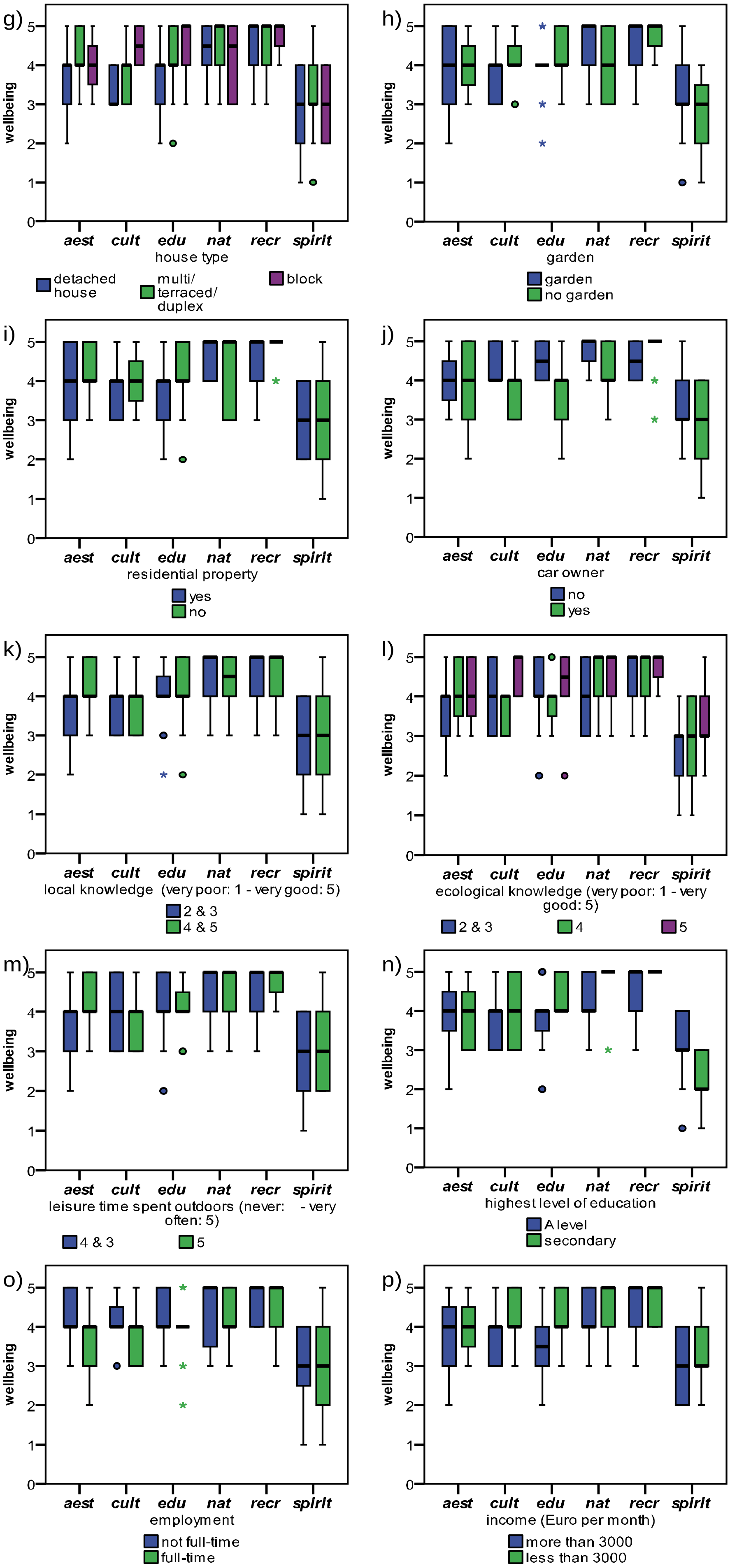

Figure 18: continued from page 77.

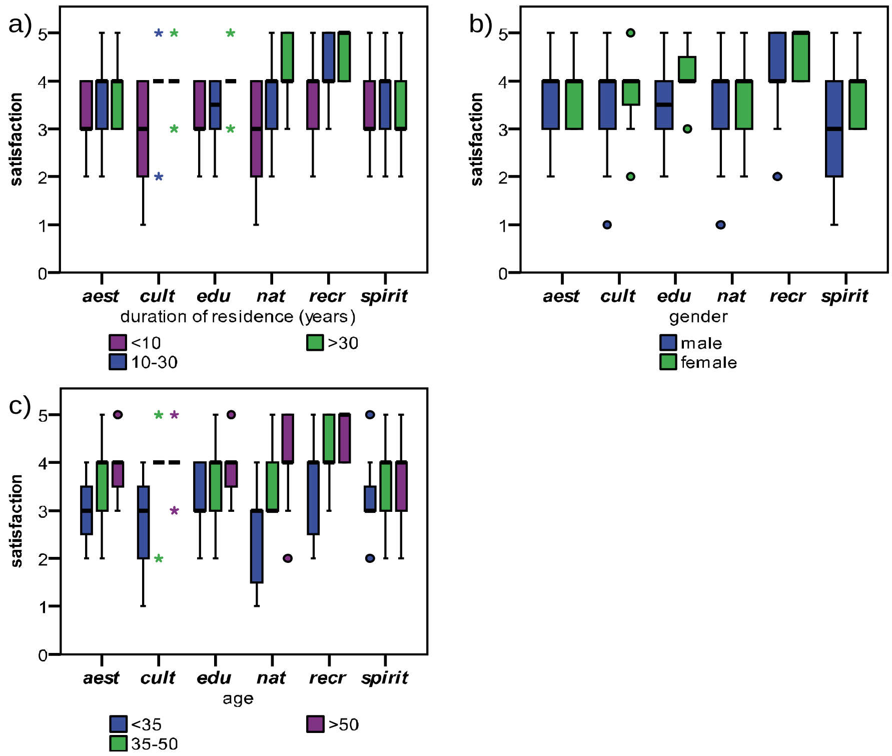

Figure 19: Comparison of satisfaction with supply (1, not satisfied – 5, fully satisfied) for the individual cultural ecosystem services aesthetics and inspiration (aest), cultural heritage and identity (cult), knowledge and education (edu), natural heritage and intrinsic value of biodiversity (nat), recreation (recr), and spiritual and religious (spirit) with regard to grouped social factors a) duration of residence, b) gender, c) age. Source: Beichler, 2015

9.4 Exploring the Spatial Link between Supply and Demand

In order to explore the spatial link between CES supply and demand, the distance to home (DTH) was calculated for the individual CES areas delineated by the participants (Figure 20). The mean value of the DTHs for nat (6.7 km), aest (4.9 km), edu (4.3 km), recr (5.1 km), and cult (3.8 km) differed significantly ($p<0.0001$). As indicated in the boxplots, the standard errors and deviations were rather high (e.g. for nat standard error: 0.4; standard deviation: 4.8), which indicated large fluctuations in the dataset. These fluctuations could be explained by the methodological design favoring outliers, as described in detail in Beichler (2015). On the one hand, zero values were related to areas in the home district. On the other hand, the maximum values differed between the individual participants. However, the maximum DTHs were around 20 km for each CES.

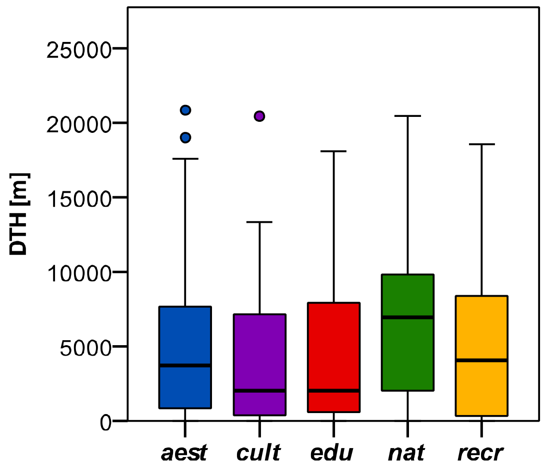

Figure 20: Distance to home (DTH) for the cultural ecosystem services aesthetics and inspiration (aest), cultural heritage and identity (cult), knowledge and education (edu), natural heritage and intrinsic value of biodiversity (nat), recreation (recr), and spiritual and religious (spirit). Source: Beichler, 2015

No linear correlation between the quality ranks for the CES areas delineated and the distance were found. In addition, no indication for a relation between the DTH and the ranking with regard to the importance for wellbeing or the satisfaction with supply was found. Moreover, one could have expected that the DTH would differ with regard to age or between participants with and without a car. However, as no relation between the DTH and any of the 16 social factors was found (cf. Beichler, 2015), the critical distances could be assumed similar for the overall population. For subsequent analyses, the median values were considered to account for outliers. These were for nat 7 km, for cult 2 km, for edu 2 km, for aest 4 km, and for recr 4 km. The districts within these critical distances of the CES areas were assumed to benefit from the services provided (cf. Beichler, 2015).

9.5 Integrated Analysis of Supply and Demand

The identified critical distances (Section 9.4) enabled to visualize an integrated CES supply-demand map. The method allows for two ways of illustrations. First, using the CES areas as output indicating how many people benefit from the CES areas. Second, using the districts as output enables to identify districts that are undersupplied. The latter was applied in Figure 21, which illustrates the total area (bigger maps) and the number (smaller maps, grayscale) of the CES areas within the critical distance. For aest (Figure 21a), cult (Figure 21c), and recr (Figure 21d), the districts in the north (at the coast) were associated with a large area of CES. Whereas the city districts in the center

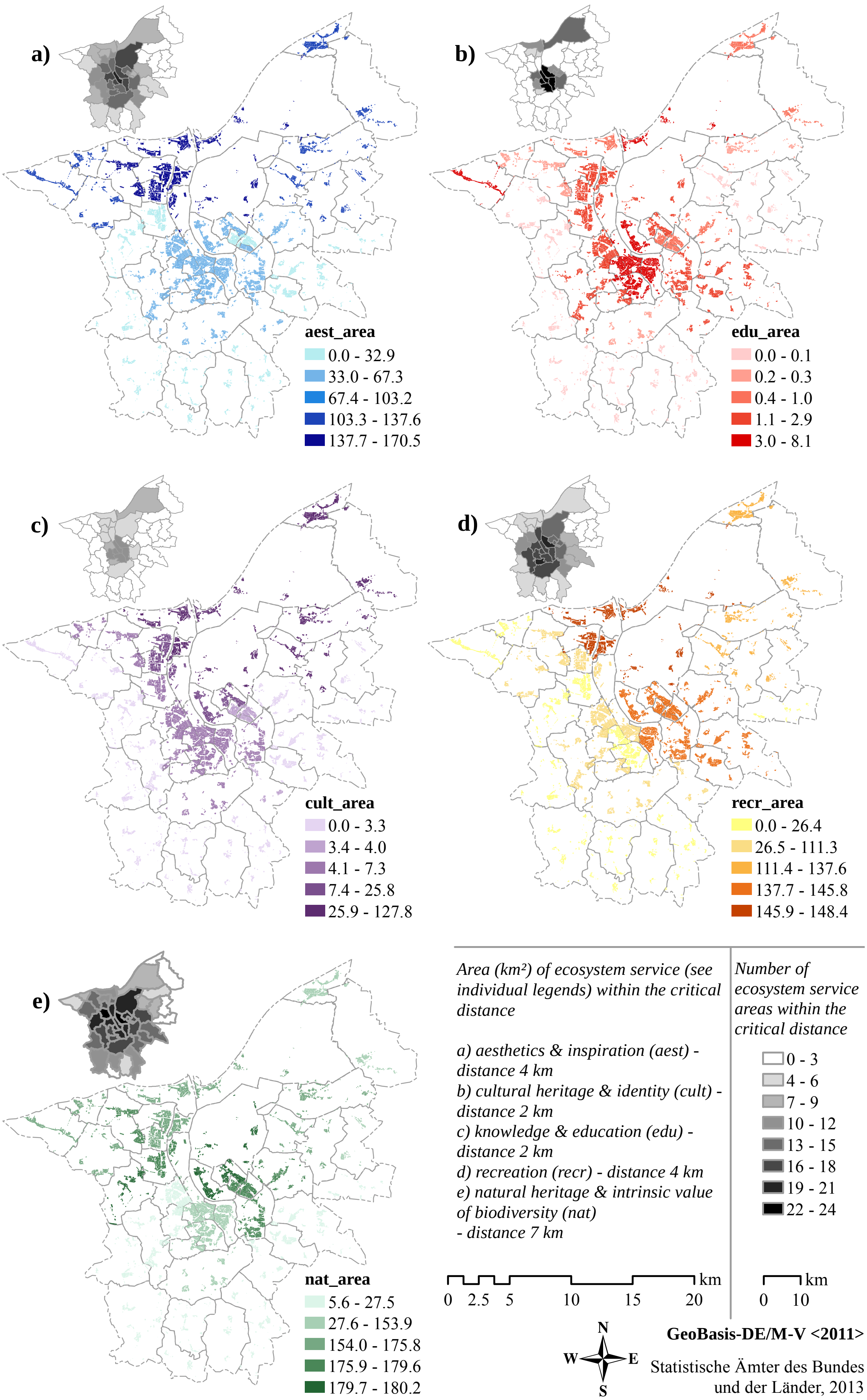

Figure 21: The integrated supply-demand map showing the supply of the individual districts in terms of number (small maps) and area for a) aest, b) edu, c) cult, d) recr, e) nat (see legend). The darker the color/grey, the bigger the values.

were associated with medium values in terms of area, but the highest values with regard to the number of areas. Regarding edu (Figure 21b), the hotspots in terms of CES area and number were equally distributed showing the highest values in the city centre. For nat (Figure 21e), except for some rural ones, all districts were supplied with a high number and area of nat. It needs to be acknowledged that the results for the outer rural districts were not as reliable, as these districts are potentially supplied by CES areas outside the area under consideration (Beichler, 2015).

9.6 Quantitative Application of the Social-ecological Vulnerability Loop

For the exemplary vulnerability assessment, first, the area and the number of all CES was accumulated without weighting (Figure 22a and Figure 23a). Furthermore, the diversity of services was determined for each district (Figure 23c) indicating, which of the five CES were represented in the accumulated results. These maps served as a basis for the vulnerability assessment, wherein the areas of perceived vulnerability (Section 9.2) were excluded (Beichler, 2015). The resulting area, number, and diversity of CES indicate the current vulnerability of the population regarding a decreased supply of CES (Figure 22b, Figure 23b and d). To enable the comparison of results, the same color scheme and range was applied.

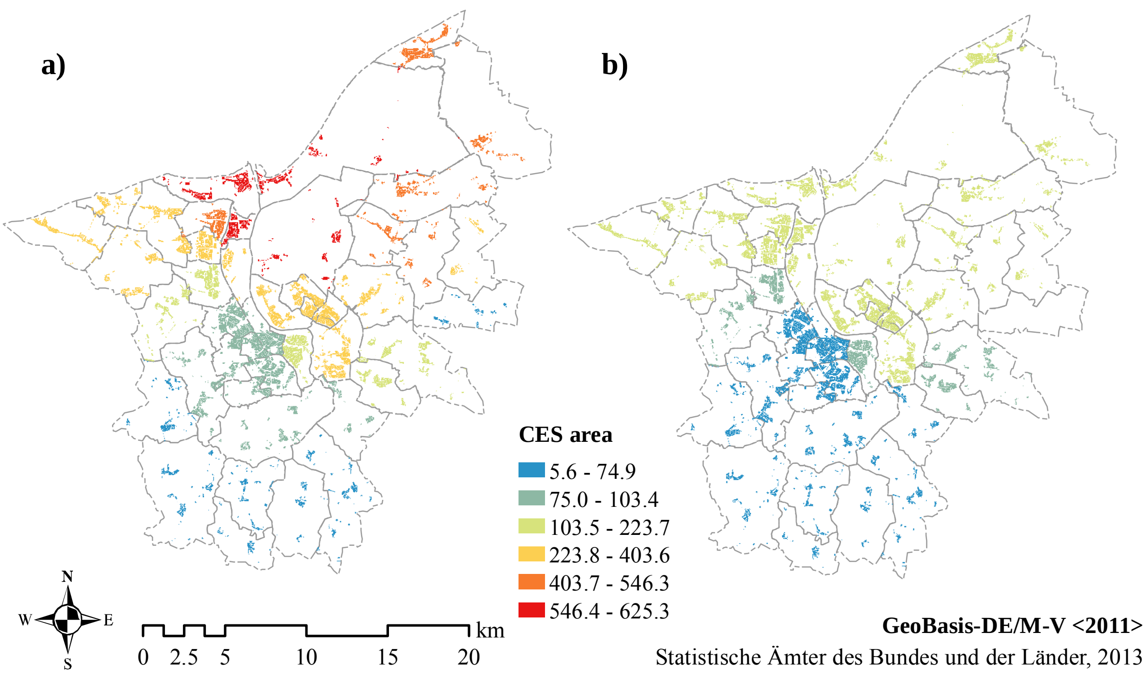

Figure 22: Integrated ecosystem service supply-demand map of a) the accumulated area in km^2 of cultural ecosystem services (CES) b) the remaining area of CES excluding areas of perceived vulnerability. Very high values are represented in red (hotspots) and very low values in blue (coldspots).

The accumulated area of CES (Figure 22a) pointed out hotspots at the Baltic Sea, particularly in the city districts Rostock-Heide, Rostock Ost, Groß Klein, and Warnemünde (for names cf. Figure 9, p. 59) as well as the surrounding municipalities in the hinterland. The exclusion of areas of perceived vulnerability indicated a considerable loss of CES area, as all hotspots disappeared (cf. Figure 22a and b).

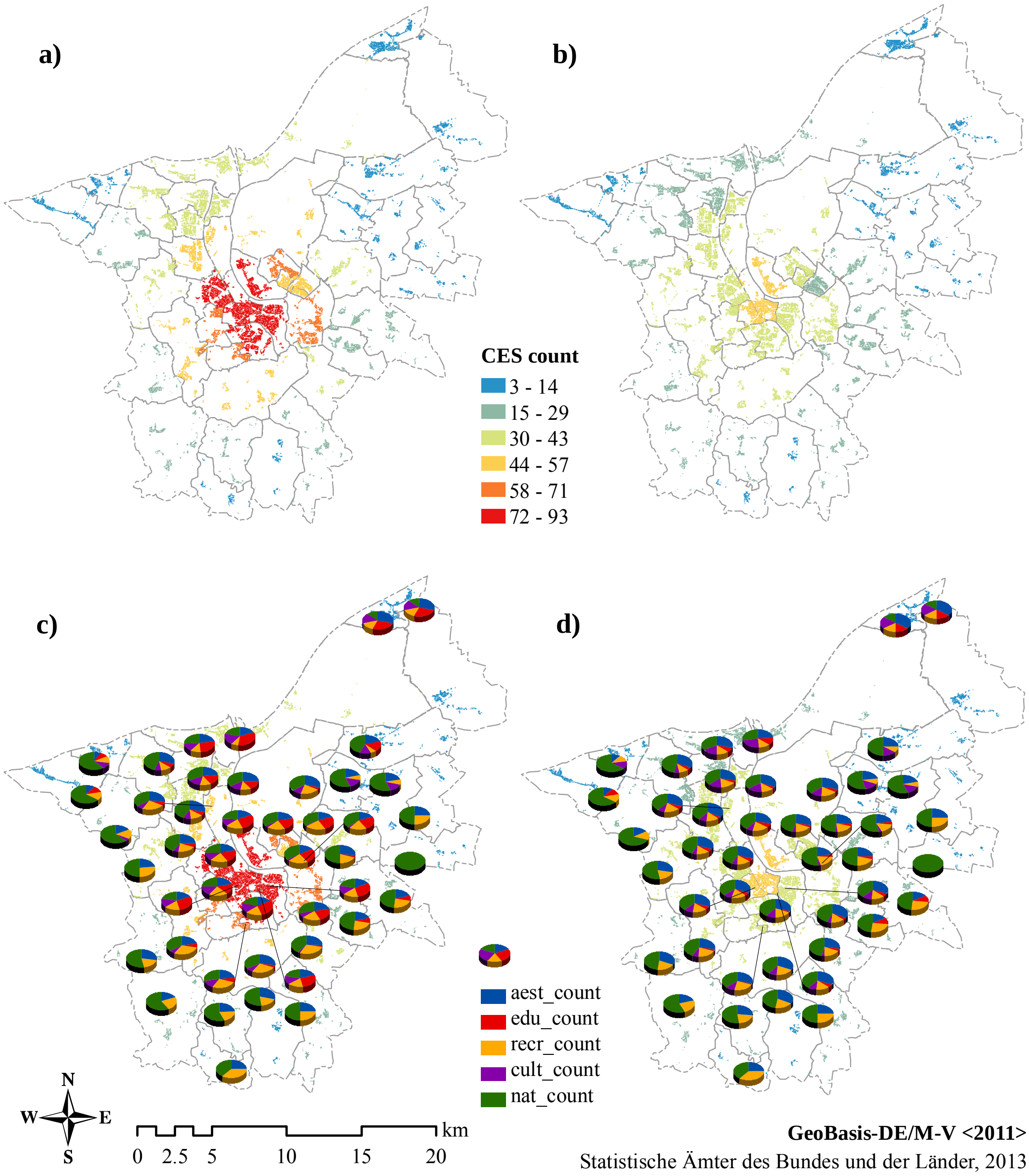

Figure 23: Integrated ecosystem service supply-demand map of a) the accumulated number of cultural ecosystem services (CES) within a critical distance, b) the remaining number of CES excluding areas of perceived vulnerability, c) the diversity of CES, and d) the remaining CES diversity excluding areas of perceived vulnerability.

Comparing the count of CES, the districts at the coast showed only a slight decline (Figure 23a and b). Yet, the hotspot of the number of CES in the critical distance was in the city centre, particularly surrounding the Kröpliner-Tor-Vorstadt. Here, a high decline was indicated, as the number of CES areas halved (Figure 23b). For most of the districts, areas of all individual CES were within the critical distance (Figure 23c). However, for some districts at the boundary of the study area, nat was very prominent, whereas edu and cult were missing.

The comparison considering the diversity of services revealed that particularly the share of cult, edu, and to some extent recr decreased (Figure 23c and d). The largest changes could be observed in the city centre, whereas for the districts at the coast, the full diversity of services was retained (e.g. Graal-Müritz). As such, the population at the coast seemed to be less vulnerable with regard to the low decrease of CES diversity and number, although for the CES area a decrease was found. The population in the city centre seemed to be more vulnerable considering the high decrease in CES number and diversity as well as the low decrease in CES area.

10 INTEGRATING DISCUSSION

This thesis' objectives are investigating social-ecological system approaches regarding climate change adaptation in the inter- and transdisciplinary context as well as developing a method for the spatial characterization of the urban region as a basis for vulnerability assessment. In this context, a reflection of literature (theoretical/conceptual part, blue in Figure 1, p. 15) and the development of methods (qualitative and quantitative application, orange and yellow in Figure 1) is ultimately intended to contribute to an appropriate knowledge base for climate change adaptation. Therefore, this section discusses the individual results of the thesis in an integrated manner. The key findings of the thesis are on the one hand reflected in the light of method development and related gaps in research. On the other hand, implications for practical application regarding adaptation are identified.

Several case studies in the context of ecosystem service research have applied participatory approaches focusing on specific areas, such as a nature reserve (Brown et al., 2012), small villages (Fagerholm et al., 2012), rural areas (Plieninger et al., 2013) or solely green areas in cities (Ståhle, 2006). The study presented here (Chapter 9) showed that a **participatory approach** is also a valuable tool for a large urban region. The integration of local knowledge has a high added value for indicator development, as the results enabled to identify and reflect upon unique characteristics of the case study area. Here, different groups were formed (environmental NGO, social NGO, planning, etc.) that could be assigned to be experts. However, no differences between the groups were found, since the group variability was comparable to the overall variance in the data. Also from observations during the study, it became obvious that participants rather referred to their role as citizens. Nevertheless, the group environment during the mapping exercise positively influenced the results (Hagemeier-Klose et al., 2014). A limitation of the presented study is that solely cultural ecosystem services were mapped, not regulating, although regulating services play a crucial role in the context of climate change (Chapter 4.3.1). However, on the one hand, the survey and the mapping of the individual CES already took between 1.5-2h. On the other hand, it has been shown that participants have difficulties to identify regulating services, since knowledge of the ecological processes is required (Brown et al., 2012). Reflecting the participatory mapping of perceived vulnerability in this context, it could be assumed that it is easier for people to map out areas, where regulating services are missing, as this can be directly perceived. In addition, the mapping of regulating services can be done based on literature, making best use of the knowledge available (de Groot et al., 2010). Here, especially for cities, sound indicators and empirical studies have been established (Haase et al., 2014). In contrast, for mapping of cultural ecosystem services, the involvement of stakeholders is strongly recommended (Fagerholm et al., 2012; Hernández-Morcillo et al., 2013). Hence, as signalized by means of the knowledge loop, the integration of local knowledge in the research process enabled to reflect and validate results. In the context of social-ecological systems theory, cultural ecosystem services are particularly recommended to identify social-ecological linkages and bridge the gaps between disciplines (Milcu et al., 2013). Besides the contributions to the scientific understanding, due to their high societal relevance, cultural ecosystem services represent the service group most effective for stakeholder engagement (Milcu et al., 2013). Through the combined mapping of cultural ecosystem services and perceived vulnerability in the presented study, the participants became aware of the potential value of ecosystems and potential impacts of climate change. The recognition, framing, and discussion of problems already present an adaptation, as the adaptive capacity increases (Chapter 8).

The results of **the land use analysis** revealed that also streets, housing area, etc. were included in the spatial units providing ecosystem services (Chapter 9.1). Thus, the results are associated with the uncertainty, whether or not the participants referred to an ecosystem. As discussed in Chapter 4.2, definitions of ecosystem vary and for the assessment, the definition of an ecosystem depends essentially on the scale (Andersson et al., 2015; Beichler et al., 2017). Interestingly, the size of the area and the quality value were not correlated and no clear minimum size for the service providing unit was found. Hence, for a participatory approach, it needs to be acknowledged that people do not think in scales and the participants did the mapping based on personal experiences, thus could have located e.g. a pocket park even though it was not displayed on the map, because of its resolution. In order to validate the CES areas mapped, ground truthing would be needed, which was here, due to the required investment of time and human resources, not possible. Nevertheless, the results present a good starting point for future research on the relative importance of different urban structures for the provision of ecosystem services. This could help to close the research gap regarding underlying mechanisms that characterize the complex dynamic interactions between social and ecological structures and processes (Alberti, 2005; Mörtberg et al., 2012; Reyers et al., 2013). By this means, urban planning could be informed on the one hand with regard to the potential interaction of green and grey infrastructure, influencing for example the microclimate (Tiwary and Kumar, 2014). On the other hand, due to the scarcity of ecosystems and the high population density in the urban centre, even very small ecological elements such as street trees, green pavements, and green roofs provide ecosystem services that are of relevance for urban planning (Gómez-Baggethun and Barton, 2013). A recent study concluded that roadside vegetation contributes to the provision of multiple ecosystem services with synergies between regulating, habitat, and cultural ecosystem services (Säumel et al., 2016). Also novel or constructed ecosystems, such as green roofs have the potential to deliver various ecosystem services including local climate regulation and habitat (Oberndorfer et al., 2007). However, these novel ecosystems should not be understood as substitute for natural ecosystems, but rather as a potential measure in highly modified areas, where returning to the original ecological status is not possible (Collier, 2014; Kowarik, 2011).

In the presented case study, many **multifunctional areas** were identified in the urban region. Due to the overlap, the land use classes related to the single cultural services need to be carefully examined. The high importance of forest for the provison of nat, cult, recr, and aest goes in line with other studies on CES and on other groups of ecosystem services (Burkhard et al., 2012b; van Berkel and Verburg, 2014). Furthermore, the findings regarding agricultural area and recr are confirmed by a study among European stakeholders, which revealed that agricultural food production relates to recreation and tourism (Maes et al., 2011). In the European context, agriculture is deeply rooted thus relates to tradition and self-image, which is also reflected in EU policies on cultural landscapes. Yet, this relation depends on the type of agriculture, since peoples preferences are associated rather with structurally divers cultural landscapes than with monocultures (Maes et al., 2011). The link to similar land use classes (especially for high value services) as well as the spatial overlap between individual CES indicated that the CES occur in bundles and that there is no direct spatial tradeoff between the individual CES. This holds true as long as the services are complementary (e.g. nat and aest). However, at the same location, there could be rivalry, for example in nature protection areas, where recreation possibilities are restricted. The differing land use mix for medium valued CES areas could be related to the unique characteristics of urban areas (Haase, 2014). As such, with regard to the size, the CES areas were considerably smaller in the city centre compared to the rural surroundings. The relation of artificial green, inland water, and pasture to medium valued areas of nat and cult as well as to edu in general, underlines the importance of urban green and blue infrastructure for the provision of ecosystem services. This has been demonstrated in other case studies in urban regions as well (Gómez-Baggethun and Barton, 2013; McPhearson et al., 2013; Tzoulas et al., 2007). Moreover, the different land use mix for high and medium valued areas might be explained by the management related to the land use and its influence on the degree of naturalness. This can be underlined by case studies on CES showing a clear preference for more natural ecosystems (Boll et al., 2014; Peña et al., 2015). Furthermore, it could be assumed that the diversity or the mix and pattern of land use classes could be more important than the presence of a specific dominant land use type. As such, it could be that a specific land use type (e.g. an elongated water body) must be present, even if it is just a small share of the total area that is related to the CES. This connection between the composition of the landscape and ecosystem services analyzed by means of landscape metrics can be found in literature as well (Frank et al., 2013; Syrbe and Walz, 2012). Furthermore, the occurrence of settlements and roads might to some extent be a characteristic factor in the land use mix of the CES, as these land use classes indicate accessibility. Especially for cultural ecosystem services, accessibility plays an important role in the assessment (Maes et al., 2011).

The identification of land use classes associated with the supply of cultural ecosystem services enables to relate them to local urban and regional development issues. The high potential of the application of the ecosystem service concept in the context of urban and regional planning has been highlighted by multiple studies (Hauck et al., 2013; La Rosa et al., 2015; Martín-López et al., 2013). Thereby, the relation to land use is of high interest, as related maps are already an inevitable part in the development of plans (Hauck et al., 2013). The specific land use classes identified here could assist in the identification of measures directed towards increasing the wellbeing of the population by means of CES, e.g. promoting the development of urban green or forest areas. In urban and regional planning, various competing interests, such as residential development, nature conservation, economic interests, etc. need to be coupled with the need for climate change adaptation. In this regard, it is of high interest to identify win-win opportunities. For tourism and recreation, a survey among European stakeholders revealed synergies to biomass energy, flood protection, erosion prevention, protection of species, and climate regulation (Maes et al., 2011). In addition, there is already a lot of evidence showing the potential of urban blue and green areas to contribute to local climate regulation (Breuste et al., 2013b; Larondelle et al., 2014). The study presented here revealed that CES and regulating services relate to similar land use classes, such as forest, pastures, artificial green, and inland water. The development of measures directed towards climate regulation and other regulating services in combination with CES cannot only deliver an additional argument for management measures, but might also contribute to the social acceptance of climate change adaptation.

Considering the analysis of the **categorical link** between ecosystem service supply and demand, an innovative method was presented including several social factors and a ranking according to the importance for wellbeing and the satisfaction with supply in the urban region for the individual CES (Chapter 9.3). Although the need for research on the link between ecosystem services and groups of the population or social factors has been emphasized (Daily et al., 2009; Granek et al., 2010), case studies are rare. In an attempt to address this research gap, the presented method was developed and tested. Here, the importance for wellbeing, particularly subjective wellbeing, was assessed alongside the satisfaction with supply, which turned out to be a valuable factor enabling a better reflection of the results. From a methodological point of view, it was very interesting that no direct relation between the number or area of services and the importance for wellbeing or satisfaction with supply was found. That contradicts some approaches, where e.g. the frequency of points is used as a measure of importance (Brown et al., 2012). All values for the importance for wellbeing and the satisfaction with supply were remarkably high. On the one hand, there could be a positive bias as the people are proud of their home region. On the other hand, these results go in line with the high happiness index found particularly for this city region (EEA, 2009). Although the 5 point Likert scale is often used for participatory approaches (e.g. Koschke et al., 2012; Scholte et al., 2015; van Berkel and Verburg, 2014; Voigt et al., 2014), the results of this study suggest that a more detailed valuation scale would have been preferable to be able to detect potential differences in the overall high values.

In the presented study, no relevant differences in the importance for wellbeing or the satisfaction with supply according to social factors were found (Chapter 9.3). It has to be acknowledged that the number of participants was too low to be able to combine social factors to form social groups. Another shortcoming of the study was that all participants had a rather high education level, which is however often the case for participatory studies as their interest in attending a study is probably higher. Thus, further studies to verify the results are required. Thereby, the implications derived from the explorative study could assist future research. The tendencies identified particularly for income, residence, and age suggest factors that should definitely be considered. Including the gender could assist in explaining some variance in the data, as woman had the tendency to give a higher rating. The most interesting finding in the presented study is that contrary to the general expectation, no differences between people with children and without children, according to living situation (house type, access to garden, and residential property), considering car owners, and according to ecological knowledge or time spent outdoors were found.

Considering landscape ecology science, the prerequisites for knowledge to be relevant for decision making are often not met. In this regard the information should allow for interdisciplinary integration (e.g. between planning sectors) and should be useful for target setting, discussion, and reflection (Termorshuizen & Opdam 2009). After the spatial characterization in terms of CES supply (see above), the examination of the categorical link, thus the demand side, is of high relevance, as it provides information about who actually benefits from a specific service. Therewith, more specific targets can be formulated, such as promoting the development of a family friendly environment. At the same time, the results presented here suggest that other groups of the population are likely to benefit as well. In the context of climate change, it should be considered that in case of a shortage in ecosystem service supply, differences according to social factors could emerge.

Regarding the differences between the individual CES, the low importance of spirit was expected, as in Northern Germany particularly the religious values included do not play a major role and besides are related to specific buildings rather than landscape characteristics. Similar results have been found in the Dutch context (van Berkel and Verburg, 2014). Nevertheless, it is important to include spirit in assessments as the complexity of spirituality and religion could be underestimated (Daniel et al., 2012).

The high importance of recreation for wellbeing can be found in literature too (van Berkel and Verburg, 2014). Yet, it should be noted that recreation is also the most often assessed cultural ecosystem services (Daniel et al., 2012; Milcu et al., 2013; Wolff et al., 2015). Interestingly, for the urban region of Rostock, the results revealed that nat and recr are equally important and both are more important for the wellbeing than the other CES. In combination with the finding that the satisfaction with supply was higher for recr than for nat, the results suggest that promoting the development of areas that deliver nat would be beneficial for the population in the urban region. This finding underlines the benefit of evaluating both importance for wellbeing and satisfaction with supply, as it enables to identify fields of action in spatial planning. Taking up the abovementioned topic of win-win opportunities, for the urban region of Rostock, the requirements for climate change adaptation that relate to future demands could be coupled with a development directed towards the current demand for nat areas.

In this thesis, a method that gives insights into the **spatial link** between ecosystem service supply and demand was presented. The results clearly indicated that the spatial interrelations of supply and demand by means of the distance to home differed between individual CES (Chapter 9.4). Interestingly, no relation between the quality ranks of the areas and the distances was found. As such, also medium valued areas could be in the maximum distance. Furthermore, no differences according to the 16 social factors, for example according to age or between people that own cars or not, were found. However, as the results refer to distances, one limitation of the case study is that the temporal dimension could not be assessed, as the participants did not specify how they got to the CES area. Therefore, the Euclidian distance was used here in order to treat all traveling possibilities equally (pedestrian, bicycle, car, etc.). Thus, the application of the DTH in the context of ecosystem service research could be further developed by including traveling aspects, which would enable to calculate the Manhattan distance (through the network of roads, path, etc.) (Beichler, 2015). Such an approach would however require a cutback of other factors in the participatory study presented here, due to the time aspect.

Overall, the DTH results suggest that people accept a longer distance for nat (7 km), medium distances for recr and aest (4 km), whereas edu and cult should be in shorter distance (2 km). In line with the findings presented here, a study on city parks revealed comparably long distances of more than 2 km for recreation, but the majority of park users were from a distance of less than 500 m (Breuste et al., 2013b). The findings of the presented study considering the spatial link give important insights into the relations between supply and demand or service-providing-units and service-benefiting-areas, therewith contributing to filling a gap in research on ecosystem services (Bastian et al., 2012a; Syrbe and Walz, 2012; Wolff et al., 2015). The spatial link is of particular importance in the context of cultural ecosystem services, as the areas need to be visited in order to have a benefit for the wellbeing. Often such specific distances are implicitly assumed and implemented in studies by means of buffers (e.g. Niemelä et al., 2010). The results of the presented study provide an empirical basis for such methods and therefore give implications for future research. Moreover, the distances indicate, at which point the areas that provide CES are still recognized and thus used. In the context of urban planning, this information enables to reflect the effect of management measures also regarding neighboring districts.

The **integrated supply-demand maps** indicated a difference between the city and the more rural areas. Yet, for the satisfaction with supply, no significant differences considering the residence (city or hinterland) were revealed. However, with regard to importance for wellbeing, there was a trend suggesting that for people living in the city, cult is more important than for people living in the hinterland. In the same context, a tendency could be observed for edu (cf. Figure 18a). These findings are supported by the spatial distribution of the CES that indicated that the city districts were supplied with a comparably higher number and total area of edu and cult. Although the city centre was characterized by a comparably lower total area of nat, recr, and aest, the satisfaction with supply did not differ according to residence. In line with that, one could assume that for people living in the city, the number of areas and the diversity of services is essential rather than the total area. Considering nat, it should be noted that due to the comparably high critical distance (7 km), more rural areas were included, which also explained the overall high values in terms of total area for nat.

The integrated supply-demand map represents a useful complement to current studies assessing both, supply and demand of ecosystem services separately (Casado-Arzuaga et al., 2014; Kroll et al., 2012; Stürck et al., 2014). In contrast to other ecosystem services, where the spatial link could be assessed by means of biophysical variables (e.g. pollination, Schulp et al., 2014), for CES the link could be influenced by personal preferences, the cultural context, and also by the supply-demand deficit itself (Breuste et al., 2013b). The understanding of the categorical and the spatial link for CES could assist planning in prioritizing areas for management measures. The direct link opens up many new analytical opportunities. As already noted in Chapter 9.5, the method allows for two ways of illustration. Thus in order to indicate how many people benefit from a specific area, the CES areas could be used as an output. To exemplify, as shown by Palomo et al. (2013) for national parks, the social demand for ecosystem services of nearby cities should be considered in management plans with regard to the consequences for the protected area as well as the provision of diverse ecosystem services required. Furthermore, the method presented in this thesis allows for differentiating according to social factors (as discussed above) and enables to calculate the CES per person, which was not done here in order to focus on the spatial distribution. Such approaches based on distances are to some extent already implemented in spatial planning, for example to evaluate the potential use of play- and recreation-grounds, distances according to age groups are applied (Agde and Hünnekes., 2013). Another example is the calculation of the green or open space provision per capita, e.g. in a distance of 500 m for Berlin (Berlin, 2013) or 1 km for Munich (München, 2005). In this regard, a differentiation according to social factors can gives insights considering social inequities in ecosystem service supply as shown by Kabisch and Haase (2014) and McPhearson et al. (2013). This is of particular importance given that in the presented study no differences in the demand was found. Although inner city CES areas cannot be replaced by areas outside the city (Boll et al., 2014; Breuste et al., 2013b), based on the presented critical distances, longer distances should be considered in order to emphasize urban-rural interrelations. It has been shown that there is no typical rural-urban gradient in ecosystem service supply in European cities (Larondelle and Haase, 2013). Cities in most cases exhibit a higher demand due to population density, but despite the limited area, cities do not necessarily provide less ecosystem services (Kroll et al., 2012; Larondelle and Haase, 2013; Radford and James, 2013). This is supported by the findings presented here, suggesting that the provision of edu and cult is higher in the city. In addition, the results suggested that not only the total area, but also the number of CES areas could be a useful indicator for urban planning. Thus, understanding ecosystem service supply and demand along rural-urban gradients could assist urban planning in finding sustainable solutions in managing resources.

Excluding the areas of perceived vulnerability enabled to illustrate the potential use of the integrated supply-demand map in **vulnerability** assessments (Chapter 9.6). Based on the results, it was assumed that the demand for CES as well as the critical distances does not differ with regard to social factors, thus all districts were treated the same way. Nonetheless, it should be noted that the developed method would allow differentiating between social factors. As the perceived vulnerability refers to extreme events that already occur today, the results indicate the current vulnerability to drought, heat wave, and extreme precipitation. As such, the exposure variable was not future directed. Yet, this could be extended by studies on climate change impacts. For example, even though Rostock is a relatively small urban region, a considerable urban heat island effect up to 8°C, an overall increase in temperature, and a strong variability on annual precipitation quantities were found (Richter et al., 2013). In this connection, the assessment of the perceived vulnerability revealed that about 60 km^2 in the urban region of Rostock are avoided during heat waves. Especially for cultural ecosystem services, the perceived vulnerability is crucial as the service benefit is lost, if the areas are not visited (Beichler, 2015). The overlay of the perceived vulnerability and the CES areas already suggested a high vulnerability considering decreased CES supply. These findings underpin other studies that showed the impact of climate change on ecosystem services supply (Mooney et al., 2009; Schröter et al., 2005). Yet, through the integrated supply-demand map presented here, it was also possible to visualize the consequences of the loss of CES areas in a spatially explicit way. The results signalized that the vulnerability is highest for the population in the city centre, especially regarding the loss in number of CES areas and the diversity of services. For the coastal districts, a decline in CES area was found, but the overall service diversity was retained. Considering all results together, it is possible to identify not only where hotspots of vulnerability occur, but also who is vulnerable, and where adaptation measures would be most efficient. This information could also assist in prioritizing actions. Taking changes in land use as an input could inform decision-makers about the potential impact of plans.

As discussed in Chapter 3 and 4, vulnerability and ecosystem service approaches differ in the way they frame the problem. This discrepancy between studies focusing on effects on the social system, e.g. different groups of the population, and studies focusing on processes in the environmental system, e.g. consequences for functions and services of ecosystems, has also been recognized in literature (Turner and Robbins, 2008).

Vulnerability assessments are increasingly requested by decision makers in the context of climate change adaptation (Hinkel, 2011), which is also the case in the urban region of Rostock (Othengrafen, 2014). Whereas, the ecosystem service concept has rarely been implemented in planning (Albert et al., 2014; Daily et al., 2009). It has been proposed that ecosystem service studies should be more socially relevant, and user-inspired taking the requirements of decision makers into account (Albert et al., 2014; Cowling et al., 2008). Thus, the presented combination of the vulnerability approach (identifying areas with the most urgent need for adaptation) and ecosystem service maps (implying what might be enhanced) will facilitate the implementation of both of the concepts into practice. As signalized by means of the first knowledge loop, this requires an exchange and integration of scientific knowledge related to different disciplines. Moreover, the transdisciplinary process can feed back into the scientific knowledge base and enables a cross-fertilization of disciplines (Chapter 8).

Although the definitions related to vulnerability differ significantly, the assessment approaches exhibit similarities (Chapter 3.2). It is proposed here that the discussion of the elements of the social-ecological vulnerability loop (Figure 7, p. 52) makes the theoretical definition of vulnerability elements more tangible, thinking directly of spatial assessment methods (Chapter 6). In this regard, the results presented could be complemented with additional data. Here, the perceived vulnerability was used to show potential changes. Using exposure assessment or different scenarios from traditional vulnerability assessments could reveal future directed results (Chapter 3). Moreover, indicators related to sensitivity, such as demographic structure (Chapter 3.2) could be used to describe the social system and thus to reveal potential changes in ecosystem service demand (e.g. increased need for recreation). Insights into the potential change of demand would be particularly interesting, as the scales of the societal demand influence the spatial pattern of the landscape in a far less obvious way than ecosystem service provision (Cumming et al., 2012). Raising awareness, teaching, and providing knowledge about how ecological system function, can influence the demand for ecosystem services, which might lead to a change in behavior as well as in the limits related to the coping capacity. Such changes in the supply-demand feedback have consequences for the overall social-ecological system. The potential for natural adaptation is often very small in cities due to the high input and modification. In this regard, as pointed out in Chapter 4.2, research is required to describe the status of the ecological system or its integrity, which would enable to describe the potential changes in supply more precisely. Moreover, there is evidence that the change in land use could have a higher effect than climate change (de Chazal and Rounsevell, 2009; Schröter et al., 2005). Thus, the state of the social-ecological system, described here by means of supply and demand, could be extended by development scenarios, for example regarding population development. To conclude, such a set of potential indicators is rather complex, but underlines the potential cross-fertilization between scientific disciplines using the proposed framework.

The high added value of intensive interdisciplinary cooperation was also highlighted reflecting the research process in the project plan B:altic (Chapter 5). For example, the different disciplinary viewpoints uncovered the various dimensions of adaptive capacity, which are at the same time related to vulnerability, resilience, and adaptation. Knowledge, a decisive variable of adaptive capacity, is highly dynamic and thus changes during the transdisciplinary part of the assessment (Chapter 3), therefore here, a qualitative method to approach adaptive capacity was presented (Chapter 8). The decision-makers' knowledge about climate change and their understanding of the social-ecological system relates to the adaptive capacity in the response element of the proposed framework. This in turn is also associated with governmental bodies, the instruments available, and investment possibilities. Often the administrative scales do not fit to the ecological scales, where processes take place, which might lead to mismatches between ecosystem service provision and societal demand (Cumming et al., 2012). The so called "problem of fit" (Folke et al., 2007) was also discussed in the context of plan B:altic considering governance aspects (based on the scales proposed by Cash et al. (2006)) using the social-ecological vulnerability loop (Beichler et al., 2012). The reflection of the adaptation measures that are under discussion in the urban region of Rostock (Hansestadt Rostock, 2013) revealed the various jurisdictional levels involved and potential shortcomings of the single measures proposed as opposed to long-term strategies (management scale). In the context of another study in the urban region of Rostock, the stakeholders expressed uncertainty concerning adaptation options. Short-term measures that are mostly related to technical solutions are regarded as more realistic, whereas for more long-term ecosystem based solutions, difficulties in the implementation were pointed out (Othengrafen, 2014). Taking a social-ecological approach could help to overcome recurring conflicts in the context of adaptation related to short-term needs and long-term vulnerability to climate change. Thereby, response scenarios could help to identify shortcomings and prevent maladaptation. Different synergies and conflicts could arise from sectoral adaptation, which underlines the need for cross-sectoral approaches, an exploration of cross-sectoral impacts, and adaptation linkages, as well as the importance of a comprehensive strategy taking a systemic perspective (Hunt and Watkiss, 2011; Reyer et al., 2012).

For both, vulnerability and ecosystem services, the spatial assessment is accompanied with high uncertainty and maps could be misinterpreted (Hauck et al., 2013; Metzger and Schröter, 2006). However, the planning phase needs to be open for opportunities and surprises including aspects of uncertainty and complexity (Cowling et al., 2008). In this context, a knowledge exchange between science and practice (cf. Chapter 8) enables a better understanding of the social-ecological system as well as knowledge building parallel to decision-making process. In this connection, scenario planning has been shown to be an effective tool considering climate change adaptation and ecosystem services (Albert et al., 2012; Oteros-Rozas et al., 2015; Rosenberg et al., 2014). In the context of plan B:altic, the scenario process initiated a stakeholder dialog in urban region of Rostock offering a possibility to cope with challenges related to uncertainty and complexity (Hagemeier-Klose et al., 2013). This process, however, was conducted alongside the analysis presented in this thesis, thus the results could not be implemented. Nonetheless, the process provided valuable information to reflect upon the findings. It would be very interesting to further investigate the potential of the integrated vulnerability assessment including ecosystem services as proposed here in a transdisciplinary scenario process.

11 Conclusion

In order to unravel the complex characteristics of social-ecological systems and issues related to climate change, an interdisciplinary research perspective as well as transdisciplinary approaches are crucial. Against this background, the presented thesis investigated approaches from various disciplines, while reflecting upon the consideration of social-ecological aspects. This provided the basis for the development of the integrated framework: the social-ecological vulnerability loop. Hereby, the practical applicability was emphasized following the objective of developing a method for the spatial characterization of the urban region. Based on the data derived through a transdisciplinary process, methods directed towards the understanding of adaptive capacity and the linkages between ecosystem service supply and demand were applied in the urban region of Rostock. Finally, this overall research process enables to answer the main research questions formulated in the beginning:

- Which theoretical frameworks can be used to describe the vulnerability of social-ecological systems?
- How can the different concepts be integrated to describe the vulnerability of the social-ecological system and its dynamics?
- Which methods can be used to characterize the social-ecological system quantitatively as a basis for vulnerability assessment?
- How can the adaptive capacity of a social-ecological system be characterized and evaluated in the face of climate change?
- Which interrelations between the social and the ecological system can be found and what are implications regarding potential impacts of climate change?

11.1 Which theoretical frameworks can be used to describe the vulnerability of social-ecological systems?

Many studies have looked into the subjects of vulnerability, ecosystem services, social-ecological system, and resilience in the last years. Differing disciplinary dialects, which became also apparent in the interdisciplinary process, complicate a comparison. It can be concluded that all approaches conceptually overlap at some point, take inherently a social-ecological approach, and are open for application in various fields, signalizing the need for integration in order to exploit synergies. Focusing on the potential for operationalization of the different approaches in an integrated manner, the definitions of the vulnerability elements was taken rather generally considering their “everyday language use” as suggested by Wolf (2012). This rather open notion enabled an open process of interdisciplinary reflection. The comparison of vulnerability indicators revealed that in the practical application, the differences in the conceptual approaches become obscure. In this regard, a consistency among sensitivity approaches was found, yet for adaptive capacity, one could conclude that a spatially explicit assessment is not applicable at the local scale. Furthermore, through a detailed evaluation of the ecosystem service concept, focusing on the complex horizontal and vertical urban structures, valuable insights into the limits of the concept were derived. To overcome these challenges, it was argued here that future applications should address the issues of human modification and human input. Moreover, whereas vulnerability studies tend to focus on people, the direct link to social factors has so far been understudied in ecosystem service research. Here, two dimensions have been identified, the categorical link referring to the importance of ecosystem services for wellbeing in relation to social factors and the spatial link between the ecosystem service supply areas and the location of the beneficiaries. Furthermore, the discussion of the individual elements of a resilience definition enabled to identify disciplinary differences and boundaries, which in scientific publications often remain unexpressed. In this regard, insights in the ambiguous use of the word impact, the dimensions of adaptive capacity and uncertainty, and the scales that relate to the comprehension of the social-ecological system’s structural and functional properties were given. In conclusion, resilience opens up a wide perspective to approach complex coupled social-ecological systems, which is useful to reflect upon approaches. Yet at the same time, the openness hampers the development of definite assessment methods.

11.2 How can the different concepts be integrated to describe the vulnerability of the social-ecological system and its dynamics?

The DPSIR framework turned out to be a valuable tool to integrate the different concepts, as it provides a pragmatically and straightforward way to organize the vulnerability elements, structure the steps of analysis, and think about potential spatial indicators. Although the resulting framework differs from traditional DPSIR applications, due to the novel combination of concepts, it can be understood as an operationalization of the vulnerability approach and the ecosystem service approach at the same time. By untangling the main features of the social system, the ecological system, and their interactions as well as feedbacks that influence the social-ecological system as a whole, the proposed framework fosters a balanced focus on both systems. As such, the development of the integrated approach enabled to recognize important features within the existing frameworks and overcome some of the signalized problems. By taking a systemic perspective, the social-ecological vulnerability loop opens up new questions for research, wherein the concepts can mutually enrich one another.

In conclusion, the social-ecological vulnerability loop is an innovative approach to describe complex social-ecological systems, combining the vulnerability concept and the concept of ecosystem service supply and demand. It allows identifying the dynamics between the elements of the social-ecological system and to link responses to consequences for the whole system. Therewith, it creates an analytical framework for a structured analysis of essential characteristics of social-ecological systems.

11.3 How can the adaptive capacity of a social-ecological system be characterized and evaluated in the face of climate change.

Adaptive capacity has various dimensions, the short-term coping capacity related to the pressure, the long-term adaptive capacity related to the state and the impact, and the adaptive capacity in the response element. It has been highlighted that current mapping approaches could be misleading, since adaptive capacity can hardly be separated from the sensitivity factors and since knowledge, a decisive variable of adaptive capacity, is highly dynamic. To overcome these challenges here, a novel combination of inter- and transdisciplinary methods was presented. The dynamic knowledge loop explores the process of knowledge generation and exchange as well as the integration of different forms of knowledge such as scientific, local, and practical knowledge. The previous sections already pointed at the importance of the science-science loop to combine the knowledge of adaptation from different disciplines. The practice-science cooperation, which was realized through participatory mapping, revealed not solely valuable local data for analysis, but the process itself triggered reflections, discussions, and problem framing with regard to the value of ecosystems and potential impacts of climate change. The science-practice exchange of results during the scenario process in turn led in addition to a problem discussion. In conclusion, the qualitative application formed a complex picture enabling a qualitative description of the adaptive capacity, while at the same time enhancing it through the increased understanding of social-ecological system under climate change. As the adaptive capacity directly relates to the response element, a follow up study investigating the transfer of knowledge into practice-practice cooperation would be highly interesting.

11.4 Which methods can be used to characterize the social-ecological system quantitatively as a basis for vulnerability assessment?

The innovative methods developed in this thesis enable to answer the questions, how and where CES are produced and who benefits where. Just recently, this has been acknowledged as a recurring gap in research on ecosystem services (Bennett et al., 2015). It has been demonstrated that a participatory mapping can be applied in a large urban region. The investigation of the relation to land use classes highlighted differences between high and medium valued CES areas and the link to other groups of ecosystem services. Moreover, it has been shown that an evaluation of the satisfaction with supply is an important complement to evaluations of the importance for wellbeing. The developed method enables to address the research gap in the direct link between supply and demand. First, the relation between the importance for wellbeing and social factors gave insights into the categorical link. Second, the spatial link between population and CES areas was established by means of critical distances. This methodological improvement on the one hand contributes to an enhanced understanding of the supply-demand relationships. On the other hand, this comprehensive characterization of the social-ecological system provides a basis for vulnerability assessment. The quantitative application of the social-ecological vulnerability allowed identifying, where hotspots of vulnerability occur, who is vulnerable, and thus where adaptation measures would be most efficient.

11.5 Which interrelations between the social and the ecological system can be found and what are implications regarding climate change adaptation?

Contrary to the initial assumption, no significant differences according to social factors were found, neither for the importance for wellbeing nor for the spatial link between supply and demand. Thus, in can be concluded that the loss of CES has the same influence on the overall population. However, additional studies on this topic are definitely needed, wherefore here, potential for improvement was suggested.

Assessing the spatial distribution of CES enabled to relate them to local urban and regional development issues. In addition, through the integrated supply-demand map, it was possible to visualize the consequences of the loss of CES areas in a spatially explicit way. It has been highlighted that promoting the generation of CES is likely to create win-win opportunities in the context of climate change adaptation. In this regard, it was remarkable that recr and nat were both the highest valued CES regarding the importance for wellbeing, whereas for nat a lower satisfaction with supply was indicated. The high societal relevance of cultural ecosystem service can influence the willingness to invest into measures aiming at a multi-functional landscape. In this connection, critical distances for the individual CES as proposed here, enable to reflect measure in terms of their effect on the population, which might also be more distant (7 km for nat). In combination with the integrated supply-demand vulnerability maps, the results allow prioritizing areas for management measures. Furthermore, the integrated supply-demand map enabled to visualize differences between the city, the hinterland, and coastal areas. Hereby, it was highlighted that the total area, the number, and the diversity of services are key factors to characterize urban regions. Understanding the linkages in the social-ecological system are crucial in the context of climate change adaptation, as the detected differences along the urban-rural gradient emphasized the importance of reflecting appropriate scales of governance. In addition, changes in the supply-demand feedback (through an impact on the social or the ecological system) have consequences for the overall social-ecological system.

In conclusion, the application of the social-ecological vulnerability loop presented in this thesis can assist planning in formulating targets, identifying suitable areas, reflecting the effect of measures, and identify potential shortcomings. Furthermore, the social-ecological vulnerability loop can serve as a basis for interdisciplinary and transdisciplinary discussions. This enabled to transparently report on limitations of the study and showed, how the results of different scientific disciplines could feed into the assessment emphasizing the potential for cross-fertilization of disciplines.

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13 APPENDIX

Erhebungsbogen

Bogen 38

Wo wohnen Sie? (Gemeinde bzw. Ortsteil HRO)

....

Wie lange wohnen Sie persönlich schon in der Hansestadt Rostock?

seit dem Jahr _ _ _ _

Sie sind...? ein Mann ☐ eine Frau ☐

Wie alt sind Sie? _ _ Jahre

Wie viele Personen leben in Ihrem Haushalt?

............Personen (inkl. Kinder)	.... Kinder (0-5)
	.... Schulkinder (6-14)
	.... Jugendliche (15-18)

Was ist Ihr Familienstand?

ledig	☐	Verheiratet/ eingetragene Lebensgemeinschaft	☐
geschieden	☐	verwitwet	☐

In was für einem Haus wohnen Sie?

Ein- oder Zweifamilienhaus	☐	mit Garten	☐
Mehrfamilienhaus	☐	mit Terrasse	☐
Reihen- oder Doppelhaus	☐	mit Balkon	☐
Wohnblock	☐	Gemeinschaftsanlage	☐
		ohne Garten/Balkon etc.	☐

Besitzen Sie in der Hansestadt Rostock Grund- oder Wohneigentum?

ja, ein eigenes Haus	☐	ja, ein unbebautes Grundstück	☐
ja, eine Eigentumswohnung	☐	einen Kleingarten	☐
ja, landwirtschaftliche Flächen	☐	nein	☐

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Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Besitzen und nutzen Sie...

Pkw	☐	Kraftrad	☐
Fahrrad	☐	Monatsticket ÖPNV	☐

Schätzen Sie bitte ein wie gut Sie sich in Rostock und Umland auskennen.

schlecht	eher schlecht	mittel	eher gut	gut
☐	☐	☐	☐	☐

Wie schätzen Sie Ihr Wissen in Bezug auf Umweltfragen/Natur ein?

schlecht	eher schlecht	mittel	eher gut	gut
☐	☐	☐	☐	☐

Bitte sagen Sie uns, wie oft Sie Ihre Freizeit im Freien verbringen?

nie	selten	manchmal	oft	sehr oft
☐	☐	☐	☐	☐

Was ist ihr höchster...

schulischer Ausbildungsabschluss		beruflicher Ausbildungsabschluss	
Hauptschulabschluss/ Volksschulabschluss	☐	abgeschlossene Berufsausbildung	☐
mittlere Reife/ Realschulabschluss	☐	Fachschul-/Meister-/ Technikerabschluss	☐
Hochschul-/Fachhochschulreife	☐	Fachhochschulabschluss	☐
ohne Abschluss	☐	Universitätsabschluss	☐
		noch in der Ausbildung (Azubi, Student/in)	☐
		ohne Abschluss	☐

3

Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Wie sind Sie derzeit erwerbstätig?

vollzeiterwerbstätig (mind. 35 h)	☐	Freiwilliger Wehrdienst / Bundesfreiwilligendienst	☐
teilzeit- oder stundenweise	☐	in Ausbildung (Azubi, Student/in)	☐
arbeitslos/auf Arbeitssuche	☐	Hausfrau/Hausmann	☐
in ABM oder Umschulung	☐	Mutterschafts- /Erziehungsurlaub	☐
Rentner/Rentnerin	☐	aus anderen Gründen nicht erwerbstätig	☐

In welchem Wirtschaftszweig / Fachbereich arbeiten Sie?

....

Wie viel Geld hat Ihr Haushalt monatlich zur Verfügung?

Denken Sie dabei an das Netto-Einkommen aller Haushaltsmitglieder, Kindergeld, Renten, Arbeitslosengeld, Wohngeld usw.

unter 500 €	☐	1000-1999 €	☐	3000-3999 €	☐
500-999 €	☐	2000-2999 €	☐	4000 und mehr	☐

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Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Kartierung

Orte: Punkte, Wege/Strecken, Flächen/Landschaften

Legende: individuelle Stiftfarbe Bogennummer & Anzahl der kartierten Orte

Direktes Kennzeichnen der Qualität auf der Karte von 1 (sehr niedrige Qualität) bis 5 (sehr hohe Qualität)

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Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Karte Nummer 1:

Welche Orte wertschätzen Sie aufgrund von Ästhetik und Inspiration, die diese vermitteln?

Karte Nummer 2:

Welche Orte schätzen Sie aufgrund von spirituellen, religiösen oder emotionalen Werten, die Sie mit diesen verbinden?

Karte Nummer 3:

Welche Orte wertschätzen Sie aufgrund des kulturellen Erbes, der kulturellen Vielfalt und der Identität Rostocks, die diese erhalten?

Karte Nummer 4:

Welche Orte wertschätzen Sie, da diese zu Ihrer Erholung beitragen?

Karte Nummer 5:

Welche Orte wertschätzen Sie aufgrund des Wissens und der Bildung, die diese vermitteln?

Karte Nummer 6:

Welche Orte wertschätzen Sie aufgrund der biologischen Vielfalt, des Naturerbes und der Natur an sich?

Schätzen Sie bitte die Qualität der von Ihnen eigezeichneten Flächen ein, indem Sie diesen einen Wert von 1 (sehr niedrige Qualität) bis 5 (sehr hohe Qualität) zuweisen. (durch direktes Einzeichnen auf der Karte)

Bennen Sie die 3 aus Ihrer Sicht wichtigsten Qualitätsmerkmale für...
Ästhetik & Inspiration: (Karte Nummer 1)
spirituelle, religiöse, emotionale Werte: (Karte Nummer 2)
kulturelles Erbe, kulturelle Vielfalt, Identität: (Karte Nummer3)
Erholung: (Karte Nummer 4)
Wissen & Bildung: (Karte r Nummer 5)
Biologische Vielfalt, Naturerbe, Natur an sich: (Karte Nummer 6)

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Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Wie wichtig sind die Faktoren für Ihr Wohlbefinden:

	unwichtig	eher unwichtig	mittel	eher wichtig	wichtig
Ästhetik & Inspiration (Karte Nummer 1)	☐	☐	☐	☐	☐
spirituelle, religiöse, emotionale Werte (Karte Nummer 2)	☐	☐	☐	☐	☐
kulturelles Erbe, kulturelle Vielfalt, Identität (Karte Nummer 3)	☐	☐	☐	☐	☐
Erholung (Karte Nummer 4)	☐	☐	☐	☐	☐
Wissen & Bildung (Karte Nummer 5)	☐	☐	☐	☐	☐
Biologische Vielfalt, Naturerbe, Natur an sich (Karte Nummer 6)	☐	☐	☐	☐	☐

Wie zufrieden sind Sie mit der Bereitstellung, den Möglichkeiten und dem Potential welches Rostocks Landschaft (Bereich der dargestellten Karte) bietet in Bezug auf

	gar nicht	eher nicht	teils-teils	eher zufrieden	voll zufrieden
Ästhetik & Inspiration (Karte Nummer 1)	☐	☐	☐	☐	☐
spirituelle, religiöse, emotionale Werte (Karte Nummer 2)	☐	☐	☐	☐	☐
kulturelles Erbe, kulturelle Vielfalt, Identität (Karte Nummer 3)	☐	☐	☐	☐	☐
Erholung (Karte Nummer 4)	☐	☐	☐	☐	☐
Wissen & Bildung (Karte Nummer 5)	☐	☐	☐	☐	☐
Biologische Vielfalt, Naturerbe, Natur an sich (Karte Nummer 6)	☐	☐	☐	☐	☐

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Appendix A: Questionnaire participatory mapping

Erhebungsbogen

Klimawandeleinflüsse und Betroffenheit

Bitte behalten Sie alle zuvor kartierten Orte im Hinterkopf

Denken Sie bei dieser Kartierung daran die Orte entsprechend zu den Klimavariablen zu Beschriften (Mehrfachbeschriftung möglich).

Karte Nummer 7:

Welche Orte würden Sie...

... während einer Dürre meiden? Bitte markieren Sie diese mit einem D

... bei starker Hitze meiden? Bitte markieren Sie diese mit einem H

... nach einem Starkregenereignis oder einer Überflutung meiden?
Bitte markieren Sie diese mit einem S

VIELEN DANK !

plan Baltic

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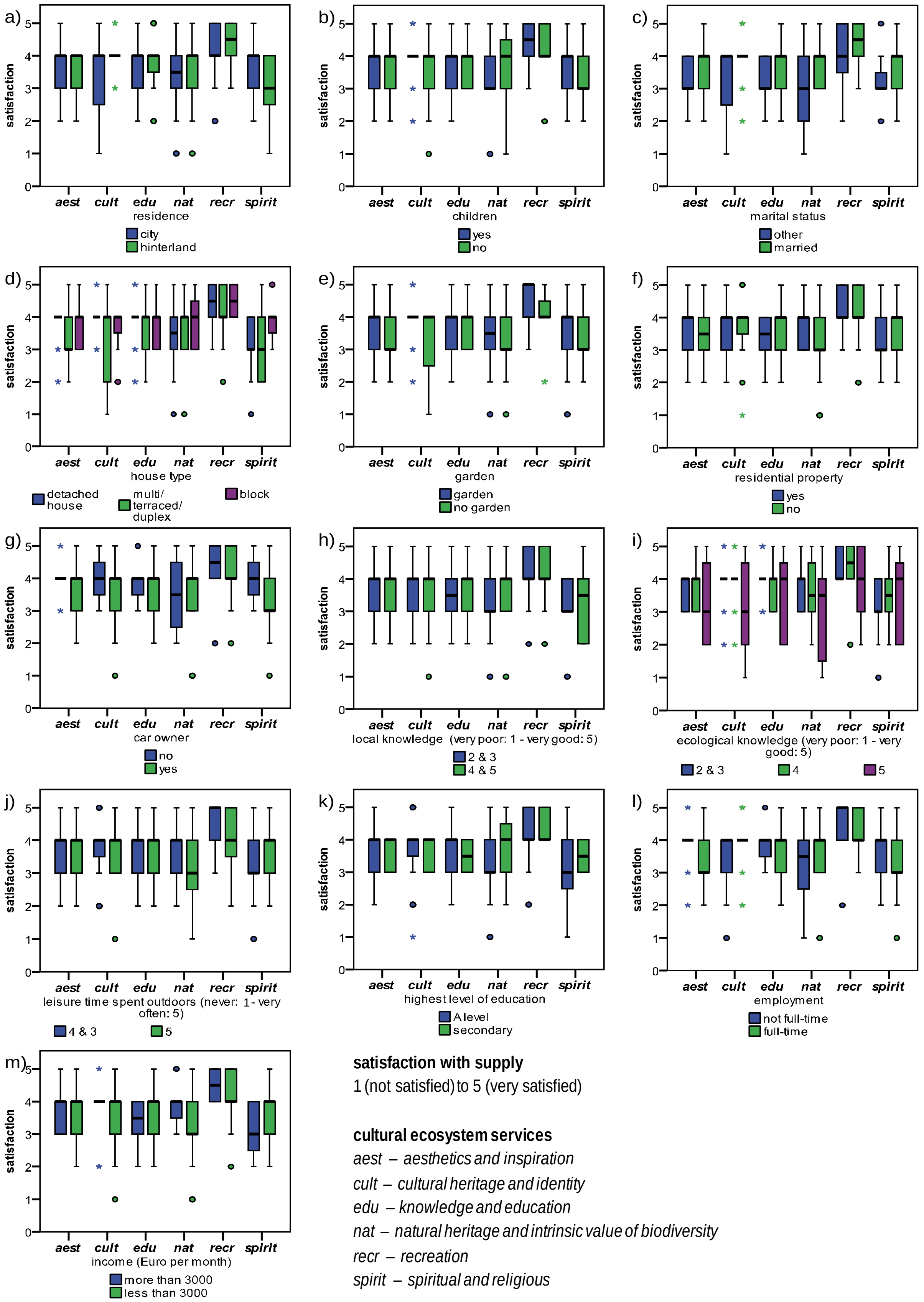
Appendix A: Questionnaire participatory mapping



Appendix B: Comparison of satisfaction with supply (1, not satisfied – 5, fully satisfied) for the individual CES with regard to grouped social factors. Source: Beichler 2015.

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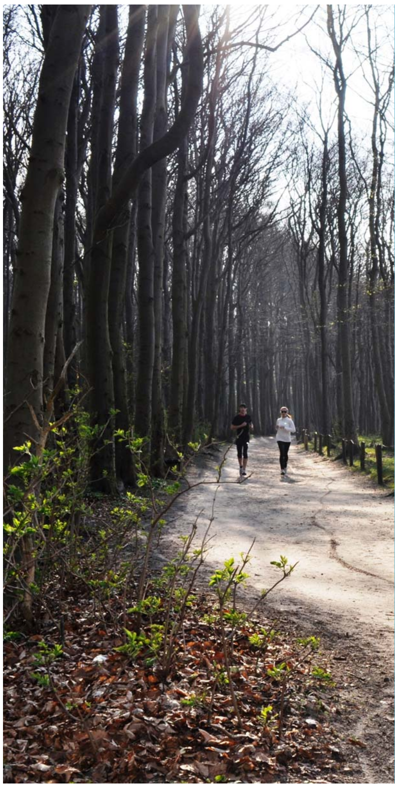

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