Applying a
Resilience Approach to Flood Management in Rapidly Changing Landscapes

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Declaration

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Abstract

Human land use activities have significantly changed the capacity of ecosystems to deliver essential service. Additional stresses brought about by climate change will require a shift in how ecosystems are managed. Global increases in the magnitude and frequency of flood events in particular have raised concerns that traditional flood management approaches may not be sufficient to deal with future uncertainties. Resilience approaches aimed at understanding and managing the capacity of social-ecological system (SES) to adapt to, cope with, and shape uncertainty and surprise offer a possible avenue to deal with these challenges. Accordingly, through the use improved systems approaches and knowledge on floods, flood regulation services and its impact on people and infrastructure this dissertation contributes towards developing and piloting of a flood resilient management strategy. Research was carried out using three flood prone municipalities in the Eden District of South Africa as a case study.

The Millennium Ecosystem Assessment, in its final report, highlighted regulating services as some of the most important and degraded, but least understood ecosystem services. Regulating services moderate the flow of energy and materials and play a critical role in regulating the impacts of extreme events. The progress in research and understanding of regulating services was investigated, with a particular focus on progress on their assessment and quantification. Findings flag key research gaps in all regulating services in developing countries and globally, in specifically understudied regulation services of disease regulation and air quality regulation. Results also revealed the need to include the human dimension into the study of regulating services, which will require an increase of multi-disciplinary research using a social-ecological system approach. Based on these findings and the objectives of the study the use of an existing decision support tool SCIMAP was adapted and explored using globally available data to provide a practical and informative approach for identifying flood receiving areas at a watershed scale. Model outputs highlighted how the combined effect of natural and anthropogenic factors can aggravate or attenuate a flood event, adding valuable insights into flood generation and how it can be managed, especially in under resourced areas. In order to assess the resilience of communities to floods, a composite index and spatial analysis approach was piloted. The approach allows for a simple, yet robust index able to include an array of datasets generally available in flood prone areas with potential to disaggregate and trace variables for management and decision making.

Finally, based on the methods and results developed in previous chapters of the dissertation, an approach to characterise and spatially connect the flood regulating ecosystem service flows from supply to demand is introduced and illustrated. The proposed method builds on from the thinking in flood vulnerability and incorporates landscape connections from supply to demand areas. By identifying and linking supply areas to the downstream benefitting areas of the watershed, areas directly linked to high demand can be conserved to ensure a sustainable supply of the flood regulation service. This dissertation provides new and improved approaches for building and managing flood resilient watersheds. The results have immediate applicability to landscape managers in areas where data for process-based models and the capacity to interpret model outputs may be limited.

KEYWORDS:

Flood regulation, ecosystem services, flood risk management, ecosystem management

Opsomming

Menslike grondgebruik aktiwiteite het die kapasiteit van ekosisteme om noodsaaklike dienste te lewer aansienlik verander. Bykomende spanning as gevolg van klimaatsverandering noodsaak 'n verskuiwing in hoe ekosisteme op die oomblik bestuur word. Globale stygings in die grootte en frekwensie van vloede in besonder wek kommer dat tradisionele vloed bestuursbenaderings nie voldoende sal wees om toekomstige onsekerhede te verweer nie. Veerkragtigheid benaderings wat gemik is op die verstaan en bestuur van die kapasiteit van sosiaal-ekologiese sisteeme (SES) om aan te pas verassings te hanteer, en onsekerheid te verweer bied 'n moontlike oplossing om met hierdie uitdaging om te gaan. Gevolglik, deur die gebruik van 'n verbeterde stelsels benaderings en kennis oor vloede, sovel as oorstromings regulasie dienste en die impak daarvan op mense en infrastruktuur dra hierdie dissertasie by tot die ontwikkeling en bekendstelling van 'n vloed veerkragtig bestuurstrategie. Navorsing is uitgevoer met behulp van drie vloedliggende munisipaliteite in die Eden Distrik van Suid-Afrika as 'n gevallestudie.

In die finale verslag van die Millennium Ecosystem Assessment, is uitgelig dat regulering dienste een van die belangrikste en vervalle, maar die minste begrypte ekosisteem dienste is. Regulering van dienste matig die vloei van energie en materiaal en speel 'n kritieke rol in die regulering van die impak van ekstreem gebeure. Die vooruitgang in navorsing en begrip van die regulering van dienste is ondersoek, met 'n besondere fokus op die vordering van bepaling en kwantifisering. Bevindinge lê klem op sleutel navorsing gapings in al die regulering dienste in ontwikkelende lande sowel as wêreldwyd, in besonder, onder-bestudeerde regulasie dienste van siekte regulering en luggehalte regulasie. Resultate onthul ook die behoefte om die menslike dimensie in die studie van regulering dienste in te sluit, dit beteken dat 'n toename van 'n multi-dissiplinêre navorsing met behulp van 'n sosiaal-ekologiese sisteem benadering sal benodig word. Op grond van hierdie bevindinge en die doelwitte van die studie is die gebruik van 'n bestaande besluit ondersteunings model SCIMAP aangepas en verken met behulp van globaal beskikbare data om 'n praktiese en insiggewende benadering vir die identifisering van vloed ontvangs areas op'n waterskeiding skaal te verkry. Model resultate lig uit hoe die gekombineerde effek van natuurlike en menslike faktore vloed gebeurtenis kan vererger of verswak, en voeg waardevolle insigte vir hoe dit bestuur kan word, veral in gebiede waar daar'n tekort aan hulpbronne is.

Met die doel om die veerkragtigheid van gemeenskappe gedurende vloed gebeure te evalueer, is 'n saamgestelde indeks en ruimtelike analise benadering geloods. Die benadering maak voorsiening vir 'n eenvoudige, maar kragtige indeks in staat om 'n verskeidenheid van datastelle oor die algemeen beskikbaar in vloedliggende gebiede te gebruik met die potensiaal om gesky te word en veranderlikes op te spoor vir bestuur en besluitneming. Ten slotte, gebaseer op die ontwikkelde metodes en resultate in die vorige hoofstukke van die dissertasie word 'n benadering gebruik om vloed regulering ekosisteem diens vloei te karakteriseer en ruimtelik te verbind van toevoer tot by aanvraag. Die voorgestelde metode is gebaseer op die denke in vloed kwesbaarheid en sluit landskap verbindings van die toevoer en aanvraag gebiede in. Deur die identifisering en skakeling van toevoer areas aan aanvraag areas in die stroomaf gebied van die waterskeiding, kan gebiede direk gekoppel aan 'n groot aanvraag bewaar word, om 'n volhoubare voorsiening van die vloed regulasie diens te verseker. Die dissertasie bied nuwe en verbeterde benaderings vir die bou en bestuur van vloed veerkragtig in waterskeidings. Die resultate het onmiddellike toepaslikheid tot landskap bestuurders in gebiede waar data vir-proses modelle en die vermoë om model resultate beperk mag wees te interpreteer.

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"So many of our dreams at first seem impossible, then they seem improbable, and then, when we summon the will, they soon become inevitable." ***-Christopher Reeve***

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Chapter 1 : General Introduction

1.1 Background

1.1.1 Climate change impacts

The world as we know it is changing at a rapid pace (Carpenter et al. 2006a). In an effort to enhance the production of food, fiber, water, fuel and mineral resources to support a growing population, humans have significantly changed the composition, structure and function of ecosystems (Rodríguez et al. 2006). One of the repercussions of this unsustainable resource use by humans has been a rapid and global change in climate. Widespread urbanisation and deforestation have changed the earth's surface, the soil moisture level and the topographic features of landmasses (Asner et al. 2004, Foley et al. 2007, Curran-Cournane et al. 2014). This has led to an alteration of regional radiation exchange and circulation patterns (Lewis 1989). There is definitive evidence that increased concentration of naturally occurring atmospheric greenhouse gases is trapping thermal radiation from the earth, causing an increase of the earth's surface temperature (Mitchell 1989). According to Walther et al., (2002) the Earth's climate has warmed by approximately 0.68°C over the past 100 years with two main periods of warming between 1910 and 1945 and from 1976 onwards. These rising temperatures are expected to have significant impacts at a global, regional and local scale.

The increase in temperature is of particular concern due to the sensitivity of a variety of systems to variability in climate (Scheraga and Grambsch 1998). This includes amongst others human and animal health, ecosystems and socioeconomic systems (Harvell et al. 2002, Patz et al. 2005, Feehan et al. 2009). According to Tompkins and Adger, (2004) the effects of climate change will likely manifest in four main ways namely; slow changes in mean climate conditions, increased inter-annual and seasonal variability, increased frequency of extreme events, and rapid climate changes causing catastrophic ecosystem shifts. One of the biggest threats represented by climate change is that it impacts on ecosystems with already diminished capacity to deliver essential services (Bozelli et al. 2009, Mooney et al. 2009). Ecosystem services (ES) are the benefits people obtain from ecosystems and can be classified into four broad categories of provisioning (e.g. food, fuel,) regulating (e.g. erosion and climate regulation), cultural (e.g. aesthetic value) and supporting services (e.g. life cycle maintenance). Social-ecological systems (SES) are interdependent systems of people and nature (Levin et al. 2012). Climate change interacts with existing anthropogenic stressors like land use change, fire regime alterations; alien invasion and infectious diseases which may compound the effects and push the social-ecological system beyond its ability to function properly and continue to support biodiversity and the benefit flows to people (Parmesan et al. 2003, Christensen et al. 2006, Carroll 2007). It is thus imperative that the effects of climate change in the context of interacting pressures and their influences on social-ecological systems be considered. The focus of my research is on the effects of climate induced change on ecosystem services, particularly water flow regulatory services, which are some of the most important services related to water security (MA, 2003).

1.1.2 Ecosystem service flows

The ability of ecosystems to provide services and the demand for those services are in constant flux and evolve as population, land use and management practices change over time (Baral et al. 2013). In Villa et al.(2014) the system dynamics of ecosystem services are summarised as "the interaction of *production* (of beneficial goods or services at the ecosystem side), *use* (uptake by beneficiary groups in societies) and *flow* (transmission of benefits from nature to humans)". Quantification of service flows offers an opportunity to distinguish between modelled capacity of ecosystem to supply a service and the actual service provision (Bagstad et al. 2013). The quantification of ecosystem service flows is also important for predicting the impact of environmental change and management on ecosystem services (Mouchet et al. 2014). To ensure sustainable provision of ecosystem services with minimal unintended consequences a better understanding of the capacity of ecosystems to generate services, as well as where services are generated and used is required (Schröter et al. 2014).

1.1.3 Flood regulating services

Intact landscapes are able to intercept and store water from rain storms and slowly discharge it in a process known as flood regulation, which forms part of the benefits humans receive from nature (MA 2003). When functioning optimally it allows for natural drainage, buffering of extremes in discharge and channel flow regulation (Ziegler et al. 2007, Simonit and Perrings 2011). Any hydrological process depends on some factors or combination of factors, which controls its activation, intensity and deactivation (Ambroise 2004). Heterogeneity in vegetation types, soil, and slope influences the function of water flow regulation (Le Maitre et al. 2007, Pert et al. 2010). It is therefore the dynamic interrelation and interdependence of all of the hydrological processes within the catchment that will determine how it responds during a rainfall event. This implies that any changes in land cover, particularly alterations that change the water storage potential of the system, can strongly influence the timing and magnitude of runoff, flooding and aquifer recharge (Bellot et al. 2001, MA 2003). Most landscapes have largely been degraded and fragmented by human land-use activities e.g. agriculture and urban development which have disrupted the ecosystem's natural flood regulatory capacity (Bronstert et al. 2002, Pattison and Lane 2012). This has led to increased losses with critical environmental, social and economic consequences for communities living in flood prone areas (Leconte et al. 2003). Due to these developments the need for adequate flood control and protection is continually increasing. To ensure the well-being of flood exposed communities, adequate flood risk management strategies should be put in place.

1.1.4 Flood risk management

Recent increases in the magnitude, frequency and duration of flood events have increased awareness of the need for improved flood risk management worldwide (Bronstert et al. 2002, Posthumus et al. 2008, Wheater and Evans 2009). By conserving, improving and managing landscapes one can protect watersheds and improve soils and thereby regulate water flow and quality, prevent soil erosion, influence rainfall regimes and local climate and maintain ecosystem health (Kremen and Ostfeld 2005, Goldman et al. 2007, Gordon et al. 2010). Floods are generated when landscape runoff delivered to the channel network exceeds its capacity to convey runoff to the catchment outlet, leading to the inundation of floodplain areas (O'Connell et al. 2007). Flood events form part of the natural disturbance regime and is important in determining ecosystem structure and function (Poff 2002, Vidal-Abarca et al. 2014). Changes in the frequency of flooding may however disturb the equilibrium of landforms and ecosystems (Poff 2002, Death et al. 2015). In order to minimize the risks posed by extreme flooding, proactive or reactive measures can be put in place (ten Brinke et al. 2008, Palmer et al. 2009). Proactive measures are actions that, if implemented, will improve the capacity of river systems to absorb disturbances while minimizing threats to the environment and human populations. Whereas reactive action involves responding to problems as they are generated by repairing damage or by mitigating ongoing impacts. The ideal is to be able to anticipate change and adapt river management to those changing circumstances, whilst having disaster relief, flood control infrastructure and evacuation plans in place (Schelfaut et al. 2011). Very specific proactive management and restoration is required to enhance resilience of ecosystems (Prior and Hagmann 2013). A good understanding of how ecosystems regulate hydrological flows and the impact of driver interactions on social-ecological systems and their regulation capacity will help to identify the best mitigation measures for a particular watershed. This is the focus of my research, which aims to increase this understanding through a systems approach to flood risk management.

1.1.5 Systems approach to management

According to Nelson et al., (2006) any change in the functioning of an ecosystem service can be attributed to the combined effects of direct drivers that are amplified by synergistic actions and feedbacks. Feedback processes occur if changes in part of the system initiate changes in other components that, in turn affect the component that originally stimulated the change (Hannon and Ruth 2001). Generally there are two feedback processes which affect system behaviour, the one being negative and the other positive (Khan et al. 2009). Negative or balancing feedbacks tend to counteract any disturbance and stabilize the system, whereas positive or reinforcing feedbacks tend to result in changes in other components that strengthen the original process and any variation in feedbacks are as a result of nonlinear relationships (Hannon and Ruth, 2001). Social-ecological systems are dynamically complex, are in constant flux, has multiple feedback processes and often change in a nonlinear fashion, where outputs are not directly proportional to input (Rial et al. 2004, Liu et al. 2007). Thus one simple change in one part of the system can produce complex effects that can cascade throughout the system (Kinzig et al. 2006). Consequently a strong enough positive feedback can lead to abrupt and rapid changes that can shift the system into an alternative stable state (Beckage and Ellinwood 2008). A systems approach offers a way to understand and possibly deal with positive feedbacks created by drivers of change on social-ecological systems, especially considering the interactions between drivers and their feedbacks.

1.1.6 Driver interaction

A driver of change can be defined as any natural or human-induced factors that directly or indirectly cause a change in a social-ecological ecosystem (Nelson 2005). These changes are the result of complex interactions between physical, biological and social factors that are so interrelated that it is difficult to distinguish between the cause and effect (Spector et al. 2001). Numerous studies have been done on individual effects of drivers of change on ecosystems (Roura-Pascual et al. 2009), but studying the effect of drivers individually is likely to either over or under-estimate the potential effects, which may lead to surprises (de Chazal and Rounsevell 2009). Hence to predict future changes and to develop policies to guide future change it is imperative that we understand the interactive effects of drivers associated with global change (Sala et al. 2000). Improved insight into how different drivers of change interact will help in identifying where and how human pressures are most likely to lead to detrimental effects on the structure and function of ecosystems (Turner et al. 2012). In areas where change is occurring rapidly and where the cumulative impacts of changes may be realized too late to trigger mitigation measures it will be particularly useful to have a model that could predict the impacts of change and provide a way to anticipate problems before they are actually observed on the landscape. In piloting such a model, my research takes a systems approach to understanding and building resilience.

1.1.7 Building resilience

Resilience is a measure of a system's capacity to cope with shocks and undergo change while retaining essentially the same structure and function (Walker and Salt 2012). When the resilience of a system is compromised, it is more vulnerable to shift to an alternative and possibly undesirable state (Scheffer et al. 2000). As mentioned earlier there are clear indications of the dramatic impacts of climate change at the ecosystem level. It is now believed that if left unmitigated climate change will likely surpass the natural capacity of human systems to adapt (Scheraga and Grambsch 1998). Measures to counteract the negative effects of climate change are thus imperative and are seen as a key element in creating a resilient society (Andrade Pérez et al. 2010). Some key concepts used in understanding and managing socio-ecological systems, relevant to my research, are vulnerability, resilience and adaptability (Chapin et al. 2010). Vulnerability is the degree to which a system is likely to experience harm owing to exposure and sensitivity to a specific hazard and the absence of the capacity to adapt (Adger 2006). Vulnerability to flood events are location-specific and dependent on the interaction between biophysical attributes and the underlying socio-economic circumstances and adaptive capacity of inhabitants (Morrow 1999, Zhou et al. 2013). Whereas resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al. 2002). Vulnerability and resilience thus have different but complimentary framings. Where vulnerability seeks to identify the weakest parts of social-ecological system to disturbance, resilience seeks to find the systemic characteristics that make systems more robust to disturbance (Turner II 2010). Adaptability refers to the capacity of a SES to respond to change in the state of a system. In a rapidly changing social-ecological system the aim is to implement strategies to reduce vulnerability to expected changes, foster resilience and increase capacity to respond to, create and shape change in a system (Chapin et al. 2010). In order to make resilience concepts useful and useable for dealing with the uncertainty of floods and future change they need to move beyond their theoretical context to a more practical piloting and use in management; an aspect I explore in this research (Walker and Salt 2012, Davidson et al. 2013).

1.2 Problem statement

The constitution of the Republic of South Africa (Act 108 of 1996) places a legal obligation on the Government of South Africa to ensure the health (personal and environmental) and safety of its citizens. Damage to infrastructure as a result of natural disasters is therefore paid for by government, and the cost involved can be great. Any private losses encountered during such an event are not covered by the government, and farmers who are often hit the hardest resort to investing in insurance to protect their assets against losses. The current disaster management practice employed in the Eden District municipalities, which constitute the study area of my research, involves investing capital in flood control infrastructure, disaster relief, and infrastructure reconstruction (Eden District Municipality 2012). In general the disaster risk management approach is to deal with the emergency after it occurs and to enact relief measures (RADAR 2010). Repetitive infrastructural failures as a result of these extreme events are eminent. In due time, municipalities will be unable to keep up with reconstruction which may leave people stranded for extended periods of time and may also increase the outbreak of diseases (Boyd et al. 2014). The communities' response to the observed changes in climate will depend on their resilience: their resources, vulnerabilities and adaptive capacities (Olsson et al. 2004, Smit and Wandel 2006). The Garden Route municipalities will benefit from disaster management practices that are more cost effective able to reduce vulnerability as well as improve the ability of the natural system to cope with continued exposure to hazards. These improved practices require better insights and projections of social-ecological systems change, drivers and impacts of that change.

1.3 Study area

The studies in this dissertation were carried out in the Garden Route catchments situated along the coast of the Southern Cape region in the Western Cape province of South Africa (Fig. 1.1). The watersheds included in the study occupy an area of 3008 km^2 and forms part of what is known as the Eden district which is an aggregation of local municipalities made up of urban centres, towns, villages and hamlets. Municipalities are politically created boundaries, sub-divided into wards which can include part of a settlement, and one or more suburbs or residential areas depending on its size. The economy in Eden is diversified but has its base in agriculture, manufacturing, tourism, trade and service (Eden District Municipality 2012). The landscape is rapidly changing as physical infrastructure development continues to take place at a remarkable rate (Tempelhoff et al. 2009). This can be attributed to a burgeoning population growth rate which is estimated at 1.56%, this translates in to 7000 new people migrating into the area each year (Eden District Municipality 2008). In recent years, the Eden district has been plagued by floods and droughts (van Niekerk et al. 2009). Both these hydrologic hazards are a consequence of extremes in precipitation (Jentsch et al. 2011). Over the last decade flood events have occurred with higher peaks and severity levels and shorter time intervals (Mélice and Reason 2007). These flood events are usually accompanied by extensive damage to infrastructure, agriculture, communications and loss of human life.

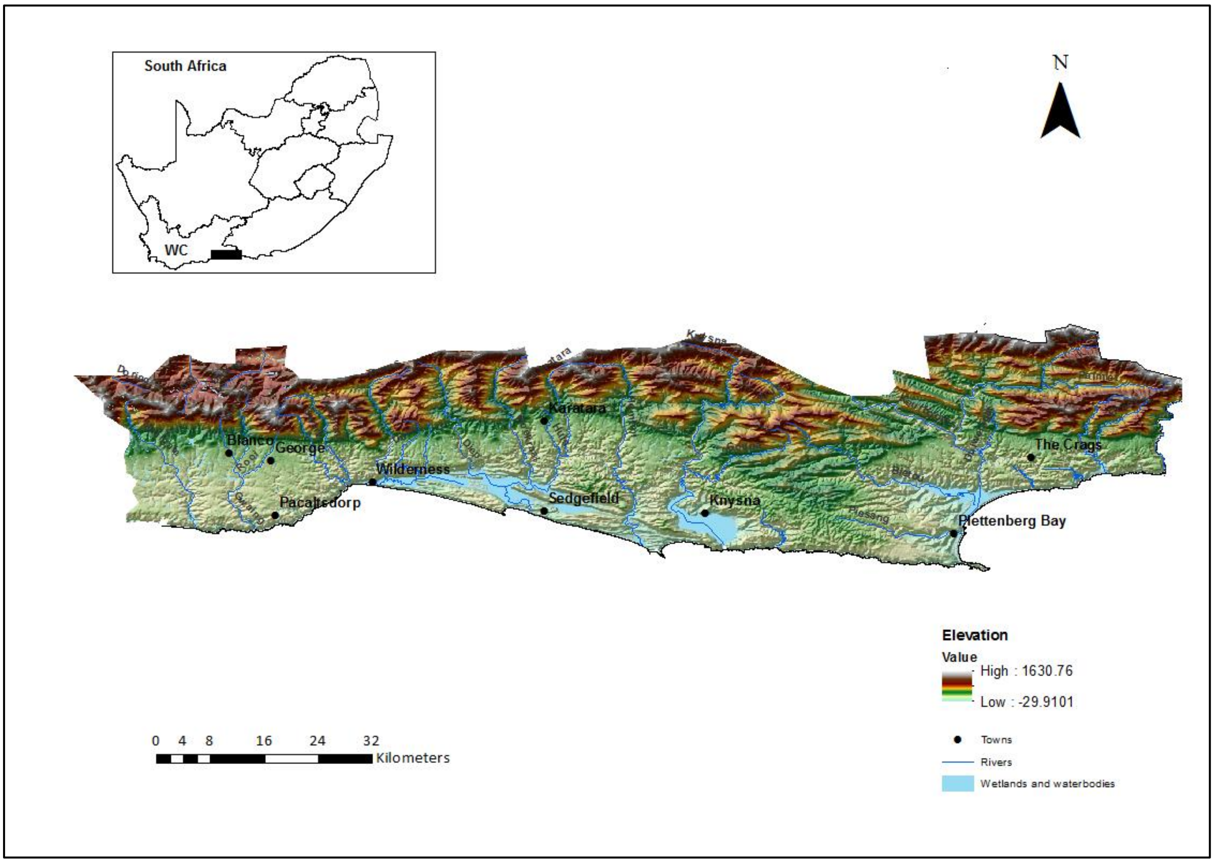

Figure 1.1: Locality map showing main towns, rivers and elevation of the study area and its location within South Africa

1.4 Objective and sub-objectives

The broader objective of this thesis was to develop and pilot a flood resilient management strategy based on improved systems approaches and knowledge on floods, flood regulation services and impact on people and infrastructure. In achieving this objective the following sub-objectives were addressed:

1) Gain a better understanding of the state of knowledge on regulating services by reviewing progress in research of regulating services since the Millennium Ecosystem Assessment, with a particular focus on progress in their assessment and quantification (Chapter 2).

2) Develop a clearer understanding of the flood generation process and how it can be managed, in especially under resourced areas. (Chapter 3).

3) Develop a practical approach to measure resilience of a system to a flood based on resilience theory and insights (Chapter 4).

4) Develop an integrated systems approach to spatially define and link the supply and demand of the flood regulating service (Chapter 5).

1.5 Structure and overview

The thesis comprises six chapters, of which four are research chapters. One chapter has been accepted in a peer reviewed international scientific journal, while the rest are in preparation for submission. I had the main responsibility of data collection, analysis and writing while my supervisor (who is also a co-author) was involved in planning of the study design, and giving of constructive suggestions and comments. In chapter 3 of this thesis there are two co-authors (my supervisor Belinda Reyers as well as Dr. David Le Maitre). Dr. Le Maitre's contribution in this paper was giving of constructive suggestions and comments. Since the research chapters are multi-authored, they are written in the first person plural (we) with the student (Ilse Kotzee) the first author in all papers. Below is an outline of the papers along with the main aims and how they were achieved. Figure 1.2 shows how the chapters are linked and related to each other.

Chapter 1 sets out the objective of the thesis and outlines the aims, scope and objectives of the research.

Chapter 2 aims to review the progress on the assessment and quantification of regulating services, ten years after the publication of the Millennium Ecosystem Assessment. This aim was achieved through a screening of 1030 abstracts and an in depth analysis of 335 published papers, covering nine regulating services. The analysis further explored progress and gaps in regulating service types and features using a conceptual framework. Chapter 2 was instrumental in highlighting gaps in the quantification of regulating services and was used to guide the focus of the three subsequent chapters.

Chapter 3 aims to garner a clearer understanding of the flood generation process by adapting and exploring the use of an existing decision support tool SCIMAP, using globally available elevation, land cover and soils data to provide a practical and informative approach for identifying flood receiving areas at a watershed scale.

Chapter 4 aims to pilots an approach to measure resilience of a system to a flood. A method is presented in which indicators are used to measure and map the spatial distribution of the levels of flood resilience across a landscape The approach entails the use of 24 indicators comprising social, ecological, infrastructural and economic aspects, which are integrated into a composite index using a principal component analysis. A fifth component of institutional resilience is used to explore levels of disaster planning, mitigation and public awareness capacities and where these can be increased.

Chapter 5 is based on the methods and results developed in chapter 3 and chapter 4 to introduce and illustrate an integrated approach aimed at characterising and spatially connecting regulating ecosystem service flows from supply to demand. The aim was achieved by spatially locating the supply of the flood regulatory service using a risk based model with outputs classified into service providing, connecting and benefitting areas. Demand for flood regulation was estimated by relating the flood hazard to exposure, and social and economic resilience of downstream areas.

Chapter 6 provides a synthesis of the previous chapters and presents the main insights gained from the dissertation relevant to the overarching objective.

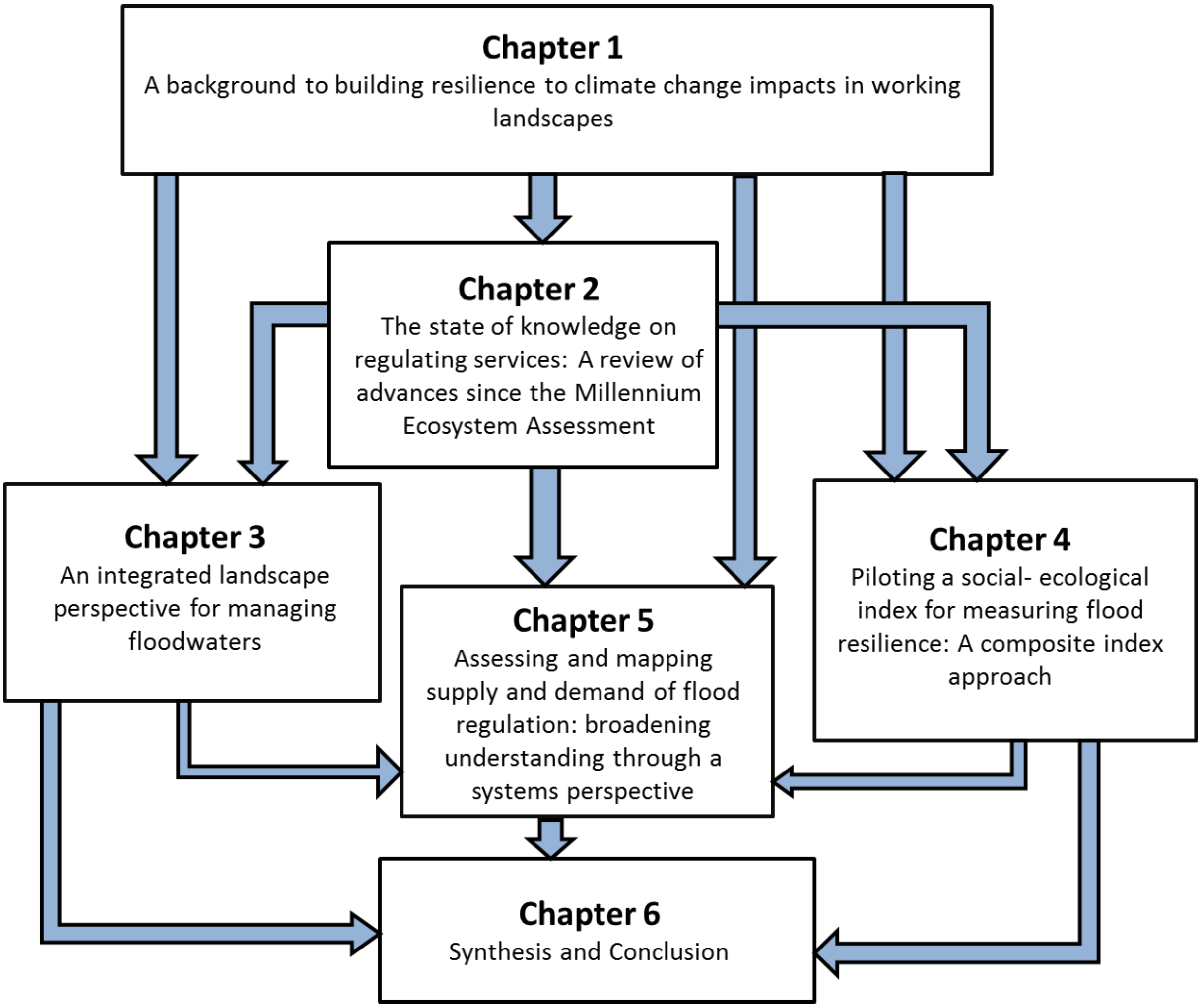

Figure 1.2: A schematic overview of how chapters of the dissertation link and relate to each other.

1.6 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field*. *Ecosystem*

Management Series no. 9 .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward.

2015a. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing

ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and*

Resources 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral*

Research 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O'Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth*

Surface Processes and Landforms 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland's valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D. Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors). Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances* *in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature’s benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell,

J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services. *Progress in Physical Geography* 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity*

12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one* 8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O’Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O’Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of Disaster Risk Reduction* 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*. *Garden*. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance. *Ecological Modelling* 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth ’s climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E. 2008. *South African atlas of climatology and agrohydrology*. Pretoria.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the “regulating” services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A multi-stakeholder approach to targeted intervention in selected municipalities*. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International …*.

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB.*

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems :

A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 2

The state of knowledge on regulating ecosystem services: a review of advances since the Millennium Ecosystem Assessment

This chapter is intended for submission to the journal *Conservation Biology as:*

Kotzee, I.M, Reyers, B.The state of knowledge on regulating services: a review of advances since the Millennium Ecosystem Assessment

2.1 Abstract

The Millennium Ecosystem Assessment, in its final report, highlighted regulating services as some of the most important and degraded, but least understood ecosystem services. A decade later we review progress in research and understanding of regulating services, with a particular focus on progress on their assessment and quantification. The study was based on a screening of 1030 abstracts and an in depth analysis of 335 published papers which covered nine regulating services. An analytical framework was used to analyse and compare spatial scale, habitat analysed and location of the study area, country of institutional affiliation and disciplinarity, as well as methodological approach including data sources, type of analysis and indicators used. The analysis further explored progress and gaps in regulating service types and features using a conceptual framework illustrating ecosystem service flows. We found that of the nine services identified, climate regulation was the most commonly assessed, followed by water flow regulation, erosion regulation and water purification and waste treatment. Most assessments were done at patch scale as well as regional scale, with very few studies done at multiple scales. Results shows that the majority of studies focused on measuring the biophysical supply of regulating services with very little work done on the demand of regulating services. Biophysical quantification and monetary valuation were the most commonly used methods to measure and assess regulating services. These findings flag key research gaps in all regulating services in developing countries and globally, in specifically understudied regulation services e.g. disease regulation and air quality regulation. There is a need to include the human dimension into the study of regulating services, which will require an increase of multi-disciplinary research using a social-ecological system approach.

Keywords: Human well-being; social-ecological system; climate regulation; ecosystem service flows; water flow regulation

2.2 Introduction

Ten years ago the Millennium Ecosystem Assessment (MA) highlighted that regulating ecosystem services, potentially the most valuable ecosystem services, were the least understood and the most at risk from human activities (MA 2005). Regulating services, which moderate the flow of energy and materials including carbon, water and nutrients through ecosystems, play a critical role in regulating air and water quality, greenhouse gases, soil fertility and condition, the impacts of extreme events and many other aspects underpinning healthy ecosystems and societies (De Groot et al. 2002, Carpenter et al. 2006a, Simonit and Perrings 2011). Despite their perceived value, regulating services have been rapidly modified, converted, over-exploited and degraded over the last century in favour of management options with shorter time frames and immediate gains (Saad et al. 2011, Bommarco et al. 2013). The MA found many shortcomings in the biophysical quantification, monitoring and valuation of regulating services, which raised concerns for the future conservation and protection of the ecosystems that produce these services (Balmford and Whitten 2003, Kumar et al. 2010). In order to understand the limits of biodiversity loss, and the required action to maintain or restore ecosystem function, a robust theoretical basis of ecosystem service functioning is essential (Kremen and Ostfeld 2005, Carpenter et al. 2006b, Cowling et al. 2008).

Regulating services are complex in that they are determined by multiple ecosystem properties and processes which are dependent on the condition and capacity of the ecosystem to regulate, rather than just the abundance of biota and production functions more relevant to provisioning services (De Groot et al. 2002, Kienast et al. 2009). They are known to change slowly over time and usually operate over large, often spatially disconnected scales (Brauman et al. 2007, Keeler et al. 2012). This slow changing and multi-scale nature makes the measurement and analysis of regulating services challenging (Layke 2009). The consequent lack of comprehensive and reliable ecological indicators means that declines in regulating services usually only become apparent once it starts impacting other more commonly measured ecosystem services (Karp et al. 2013). Spatial location and scale also play an important role in the valuation of regulating services, as multiple ecosystem service flows imply multiple beneficiaries. In addition, many regulating services contribute to the delivery of final services, but do not affect human well-being directly (Lamargue et al. 2011, Simonit and Perrings 2011, Viglizzo et al. 2012). Conventional methods of ecosystem service valuation therefore fail to accurately quantify their value (Salzman 2005, Kumar et al. 2010).

This lack of understanding of and information on, the value of regulating services has generally led to their absence in public decision making related to the conservation of ecosystem services.

Since the publication of the MA, ecosystem services research has grown substantially (Seppelt et al. 2011, Häyhä and Franzese 2014). New technologies, combined with the growing powers of computers and the availability of tools such as Geographic Information Services (GIS), remote sensing, multi-criteria analysis and thematic mapping have made it easier to assess and account for ecosystem services (Tardieu et al. 2013, Palomo et al. 2014b). The new generation of decision support tools (e.g. Aries and InVEST), allows for replicable and spatially explicit ecosystem assessment and trade-off analysis at the landscape-scale (Bagstad et al. 2014). Progress has also been made in the uptake of ecosystem service research into policy and management (Guerry et al. 2015). Moreover, national governments, businesses and non-governmental organisations are increasingly recognising the value of ecosystem services (Crossman et al. 2009, Curran-Cournane et al. 2014). The use of economic response policies such as Payment for Ecosystem Services (PES) has seen rapid growth, with a variety of programs initiated at varying scales and locations around the world (Farley and Costanza 2010, Kumar et al. 2014). On a global scale, The Economics of Ecosystems and Biodiversity (TEEB) was launched to draw attention to the global economic benefit of biodiversity (TEEB 2010). In 2012 the Intergovernmental Platform on Ecosystem Services (IPBES) was established with the aim of assessing the state of biodiversity and ecosystem services (ES) and to facilitate dialogue between the scientific community, governments and practitioners (Perrings et al. 2011).

Several reviews have explored the progress in ecosystem service research highlighting the availability of ES indicators, as well as approaches used to map and assess ecosystem services (Layke 2009, Seppelt et al. 2011, Martínez-Harms and Balvanera 2012) but to date none has specifically focused on the area of regulating ecosystem services. Here we review whether the interest, investment and growth within ecosystem service research and policy has had an impact on the knowledge base of regulating services, addressing the knowledge gaps highlighted by the MA over a decade ago. Using a bibliometric review, as well as an analytical framework, we quantify the progress made in research into regulating services since the MA. We focus on progress in the methods and data used for assessment and quantification in line with the needs of the upcoming IPBES regional and global assessments.

2.3 Methods

A quantitative review was performed using systematic review methodology (Moher et al. 2009) based on publications found through a bibliographic search using the SciVerse Scopus search engine, (http://www.info.sciverse.com/). Based on two of the largest global assessments of ecosystem services (MA and TEEB) we identified nine regulating services to include in the review (Table 2.1). In addition to the term 'regulating service' keywords specific to each regulating ecosystem service were selected as search terms (see appendix A for a full list of search terms). Eligibility criteria included any peer reviewed paper published between 01/01/2005 and the cut-off date 17/04/2015 with the predefined terms in the title, keywords or abstract.

An initial screening of the 1030 abstracts found in the bibliographic search was done using the online systematic review software product Covidence (https://www.covidence.org/). Covidence is a freely available online systematic review software used to streamline and facilitate a review process. The elements of the software used in this review include citation importing and screening of abstracts found in the bibliographic search. Articles were excluded if they were (i) not related to regulating ecosystem services, or (ii) mentioned the term "regulating service", without actually addressing regulating services in the article. Approximately 17% of the original papers were excluded at this stage. Papers dealing with regulating services and those whose content was unclear from the abstract alone were retained for the next round of screening. The remaining 846 papers were included in the second screening which consisted of a full text reading. A further 35% of papers were excluded after this stage and consisted of papers that were (i) not related to regulating ecosystem services (186 papers), and (ii) did not have their full text available in English (118 papers). Because we were specifically interested in the state of empirical research, a subset of 335 papers that reported empirical ecosystem research were selected from the remaining 542 studies. The papers excluded at this stage were either conceptual, with no relevant empirical component (115 papers) or were literature reviews (92 papers). The remaining 335 papers became the subject of our analysis. Data were extracted from the empirical studies based on various parameters shown in Table 2.2.

Table 2.1: List and description of regulating services included in this review.

Regulating services	General description
Air quality regulation	Service provided by ecosystems through the contribution and extraction of chemicals from the atmosphere, influencing many aspects of air quality.
Climate regulation	Service provided by ecosystems through the regulation of regional climate by providing sources or sinks of greenhouse gases.
Disease regulation	Service provided by ecosystems through the regulation of the abundance of human pathogens (e.g. cholera) and abundance of disease vectors (e.g. mosquitos).
Erosion regulation	Role of vegetation, root matrix and soil biota in soil retention, prevention of landslides and erosion control.
Natural hazard regulation	Influence of ecosystem structure in reducing environmental disturbances (e.g. storm protection by coral reefs and flood protection by wetlands).
Pest regulation	Service provided by ecosystems through the regulation of the prevalence of crop and livestock pests and disease.
Pollination	Service provided by ecosystems through the regulation of the distribution, abundance and effectiveness of pollinators.
Water flow regulation	Service provided by ecosystems through the regulation of timing and magnitude of runoff, flooding and aquifer recharge.
Water purification and waste management	Service provided by ecosystems through the filtration and decomposition of organic wastes introduced into inland waters and coastal and marine ecosystems.

Several authors have highlighted that most ecosystem services assessments tend to measure only the supply side of ecosystem service delivery (Villamagna et al. 2013, Baró et al. 2015). To distinguish among the different components of ecosystem service flows, the regulating services studied were divided into properties, potentials, service flows, benefits and beneficiaries based on the Ecosystem Properties, Potentials and Services (EPPS) framework of Bastian et al., (2013). The framework is divided into three levels namely physical, intermediate and socio-economical and consists out of five pillars namely properties, potential services, benefits and beneficiaries. *Properties* are the ecological conditions, structures and processes that determine whether an ecosystem service can be supplied and is driven predominantly by natural scientific methods using analytical indicators. ***Potentials*** are the capacity to supply service (potential use) and can be regarded as the stocks of ecosystem services. The ***services*** component of the framework represents the actual flow of the service and requires a consideration of human needs or demands for the service. In order to measure how ecosystem services contribute to human well-being the ***benefits*** derived need to be analysed through a valuation process. The final pillar of ***beneficiaries*** requires the consideration of stakeholders, users or beneficiaries of the service. With the use of the framework, the ecosystem services assessed in the review was classified into the five pillars in order to highlight which component of ecosystem service flow has received the least or most attention (Table 2.2). Based on the institutional affiliation of authors, studies were classified into intra-disciplinary or multi-disciplinary studies.

Table 2.2: Criteria used to classify the types of approaches used to assess regulating services.

Criteria	Categories considered	Rationale
Data sources used	Primary	Data derived from field data, survey, interviews, remote sensing data.
	Secondary data	Data derived from atlas data, administrative statistics, data from literature, expert knowledge.
Type of analysis	Quantitative	Research used to quantify data by means of general numerical data.
	Qualitative	Primarily exploratory research, used to gain an understanding of underlying reasons, opinions and motivations.
	Mixed	A combination of quantitative and qualitative analysis.
Indicators used	Bio-physical data	Biophysical quantities eg. sediment lost in tonnes per year.
	Monetary	Monetary value for the service produced.
	Ranking	Ranking done by experts, policy makers or the general public.
Spatial Scale	Patch	$10\text{-}10^2 km^2$
	Local	$10^2\text{-}10^3 km^2$
	Regional	$10^3\text{-}10^5 km^2$
	National	$10^5\text{-}10^6 km^2$
	Global	$>10^6 km^2$
Type of habitat analysed	E.g. wetland, urban, forest	Studies categorised based on the habitat in which study was performed.
Location of the study area	E.g. Northern Europe, Southern Africa	Geographical locations in which study was carried out.
Country of institutional affiliation of the first author	Institutional affiliation	The institutional affiliation given in the author address.
Disciplinarities	Intra-disciplinary	Scholars working within a single discipline.
	Multi-disciplinary	Scholars from different disciplines working together, each drawing on their disciplinary knowledge.
Methods used	Monetary valuation	The process of expressing a value for a particular service in a certain context (e.g. decision making) in monetary terms.
	Trade-offs and scenario analysis	The identifying and quantifying of the associations between ES to predict the impact of environmental changes and management on ES supply.
	Stakeholder perception	A survey done by people and organisations that have an interest in the regulating service provided. Stating what they believe to be true.
	Expert opinion	Experts rank data based on their potential to provide specific ES.
	Biophysical quantification	Quantification based on field data.
	Content analysis	A systematic procedure for interpretation of data in order to elicit meaning, gain understanding and develop empirical knowledge.
	SWOT analysis	A structured planning method use to evaluate strengths, weaknesses, opportunities and threats involved in a project.

2.4 Results

2.4.1 Analysis of published papers

The number of papers assessing regulating services increased substantially over the last decade (Fig. 2.1 (a)). Publication rate rose from only 18 papers published in the period 2005 to 2008, to an average rate of 49 papers per year from 2009 to 2014. In the analysis, 45% of publications used data obtained from primary data sources, whereas 54% relied on secondary data sources (Fig. 2.1(b)). Quantification was the main type of analysis (81%) followed by qualitative assessments and mixed analyses (Fig. 2.1(c)). The most common indicators used were bio-physical values (71%), followed by biophysical ranking and monetary values (Fig. 2.1 (d)).

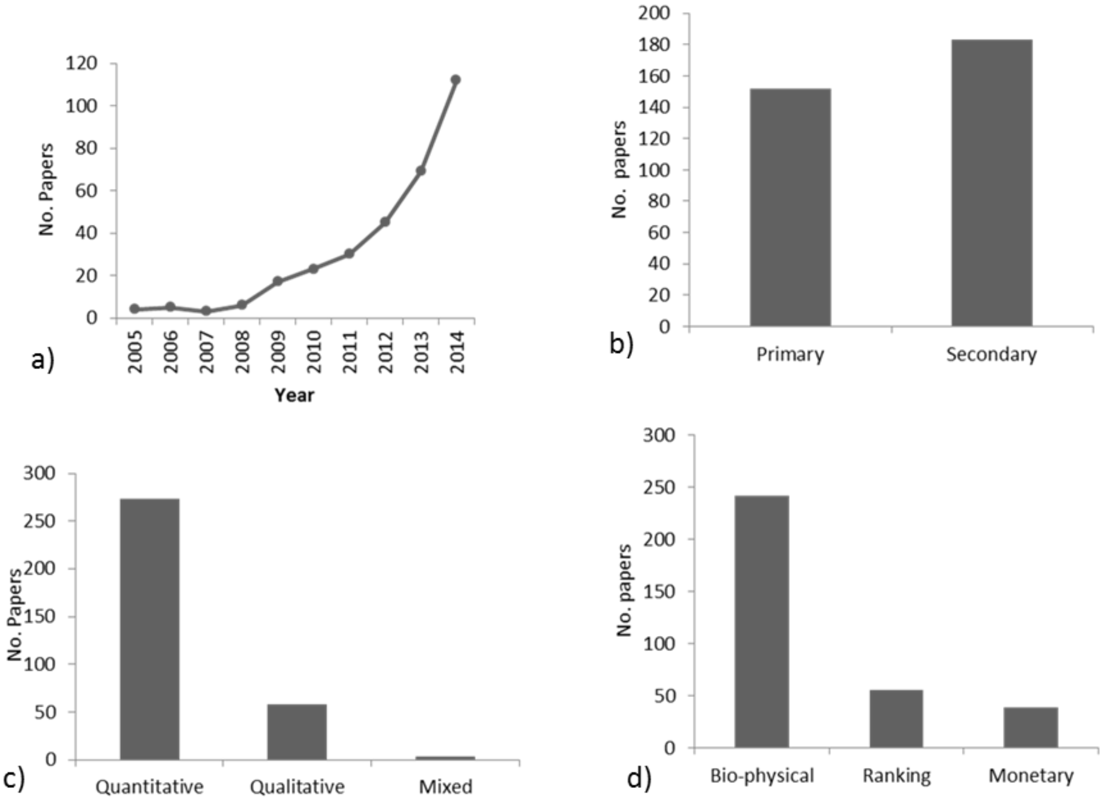

Figure 2.1: Data and analysis of 335 papers selected showing (a) Number of publications per year; (b) Number of papers using primary or secondary data; (c) Number of papers using quantitative or qualitative data; (d) Number of papers using bio-physical, ranking or monetary indicators.

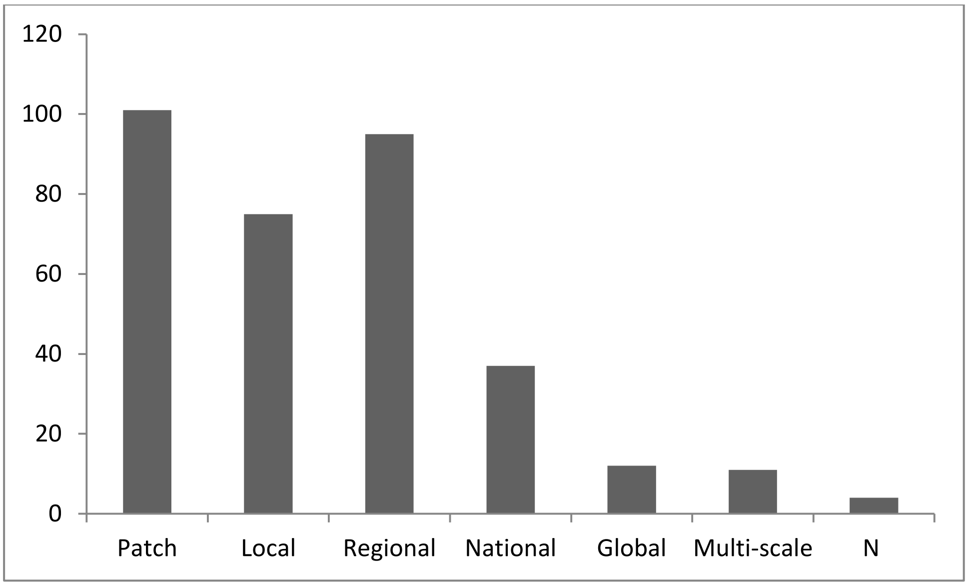

Figure 2.2: Spatial scale of the case studies found in the literature (N = no case study).

Most studies were carried out at the patch scale (30%) followed by the regional scale (28%) and local scale (22%) (Fig. 2.2). Fewer studies were carried out at national, global and multiple scales. The remaining studies were carried out in a laboratory, and therefore did not have a study location.

Studies were carried out in a variety of habitats (Table 2.3). The majority of studies covered more than one habitat type and was placed in the habitat category “mixed”. Fifteen percent of studies were carried out in the agroecosystem with pest regulation and climate regulation the most studied services. This was closely followed by the forests ecosystems in which climate regulation and water flow regulation were most commonly studied. Nine percent of research was carried out in urban ecosystems with climate regulation, natural hazard regulation and air quality regulation the most commonly studied services. This was closely followed by wetland ecosystems in which climate regulation and water purification and waste treatment were most often studied. Studies were also carried out in grasslands and freshwater ecosystems, with minimal studies carried out in the coastal zone and marine ecosystems.

Table 2.3: Matrix showing the published assessments of regulating services and the habitats in which they were measured.

Regulating service assessed	**Agro-ecosystem**	**Estuarine & Coastal**	**Forest**	**Freshwater**	**Grassland**	**Marine**	**Mixed**	**Urban**	**Wetland**
Air quality regulation	3	-	5	2	-	-	20	6	-
Climate regulation	21	7	32	4	9	3	94	27	21
Disease regulation	4	0	2	1	1	-	7	1	1
Erosion regulation	11	2	14	3	7	0	55	4	6
Natural hazard regulation	7	2	6	7	2	1	8	10	11
Pest regulation	31	2	7	3	1	0	38	4	3
Pollination	9	0	5	-	1	1	32	5	-
Water purification and waste treatment	12	3	12	7	2	2	39	6	15
Water flow regulation	14	3	16	5	10	-	39	7	5
Total	**112**	**19**	**99**	**32**	**33**	**7**	**332**	**70**	**62**

2.4.2 Distribution and disciplinarity of study

The articles analysed summed up 344 study areas, with nine of the 335 papers analysing more than one study location. The global distribution of research per geographical region is depicted in Figure 2.3. The majority of studies have been carried out in North America (17%), East Asia (13%) and Southern Europe (12%), followed by Western Europe (11%), South America (8%), Northern Europe (7%) and Australia and New Zealand (6%). In total more than 70% of studies were carried out in these 7 regions. Fewer studies were carried out in Central (1%),Southern (3%) and Eastern Africa (3%), Central America (2%), Eastern Europe(1%), and Southern(2%) and South-eastern Asia(1%). The location of 72% of studies corresponded to the country of the first author's host institution. In the remaining 28% of studies research was carried out by institutions outside the geographical region of the field study. In these instances, studies were carried out predominantly by institutions in North America, Northern Europe and Western Europe.

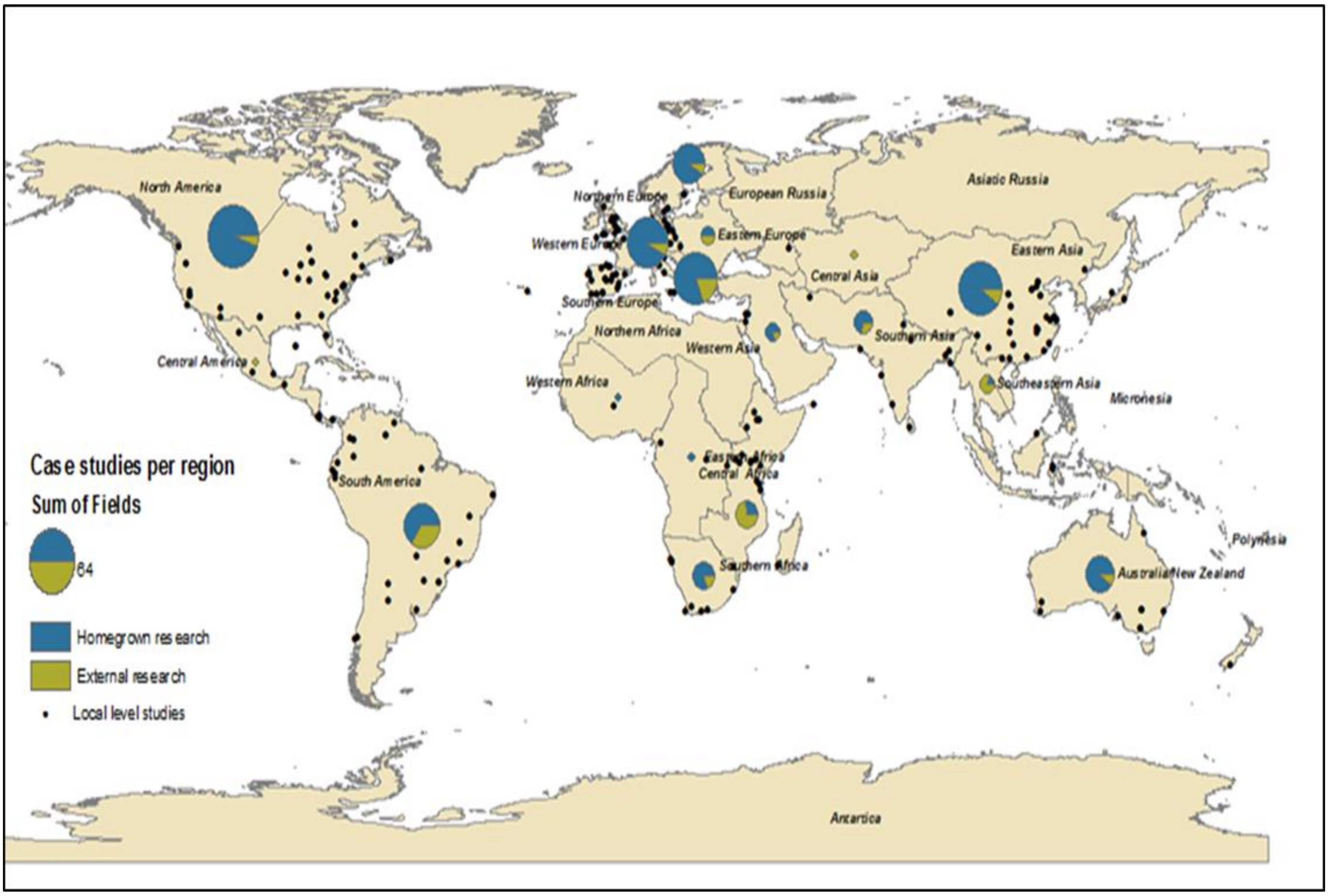

Figure 2.3: Global distribution of local scale field studies and the affiliation of the first authors. The pie size represents the number of studies carried out per region. The colours within the pie show the percentage of studies carried out by researchers from the same region (blue), or from different regions (green).

From the selected studies 74% were classified as intra-disciplinary, while 24% were classified as multi-disciplinary. In 1.5% of studies the author's affiliation was not given in sufficient detail to allow classification. The majority of multi-disciplinary studies were conducted between natural scientists and social scientists (63%), followed by research between natural scientists and engineers (17%), although marginal there were also collaborations between natural scientists and political scientists, as well as natural scientists and health care scientists or architects.

2.4.3 Quantification of regulating services and methods used

The frequency with which specific regulating services were assessed in the 335 articles is shown in Figure.2.4. Climate regulation was the most commonly assessed service, and was considered in 60% of the articles analysed. Other frequently assessed services include water flow regulation, erosion regulation and water purification and waste treatment.

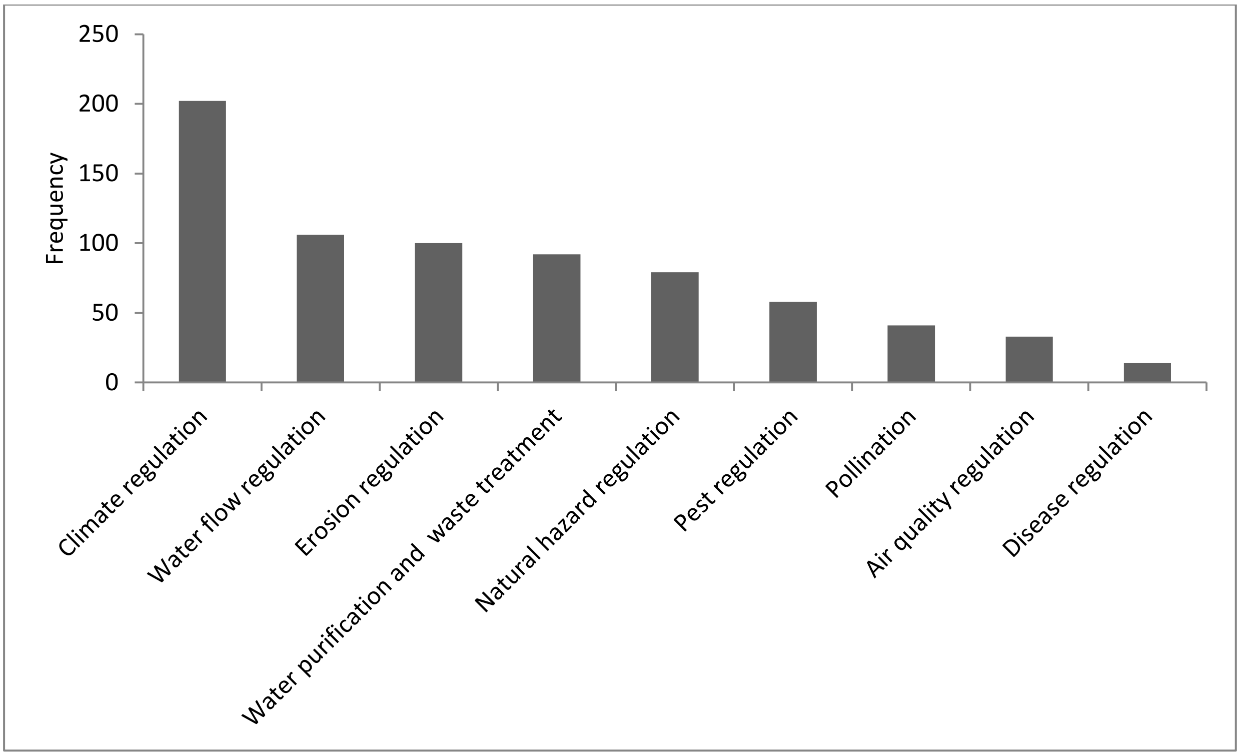

Figure 2.4: Frequency with which regulating services were considered in the 335 articles analysed.

Following the *Ecosystem Properties, Potentials and Services framework* (Bastian et al. 2013), 9.5% of articles assessed *ecosystem service properties*, whilst 57% of articles considered *ecosystem potentials*, 14% of articles analysed service flows, and 18% assessed *benefits* whilst only 3% considered the *beneficiaries* of regulating services (Fig. 2.5). Also shown in Figure 2.5 are the methods used to assess regulating service within each of the components of the framework. All of the studies in which the *properties* of regulating services were assessed made use of biophysical quantification. To assess *ecosystem service potential,* biophysical quantification was largely used, followed by trade-offs and scenario analysis, as well as expert opinion; monetary valuation stakeholder perception and content analysis. For the assessment of *service flows*, stakeholder perception was the most commonly used, followed by biophysical quantification, monetary valuation , trade-offs and scenario analysis as well as content analysis and expert opinion. To assess ecosystem service *benefits* monetary valuation was the most commonly used, followed by biophysical quantification, stakeholder perception, trade-offs and scenarios analysis and SWOT analysis. To assess ecosystem service *beneficiaries* biophysical quantification was largely used, followed by stakeholder perception and trade-offs and scenario analysis.

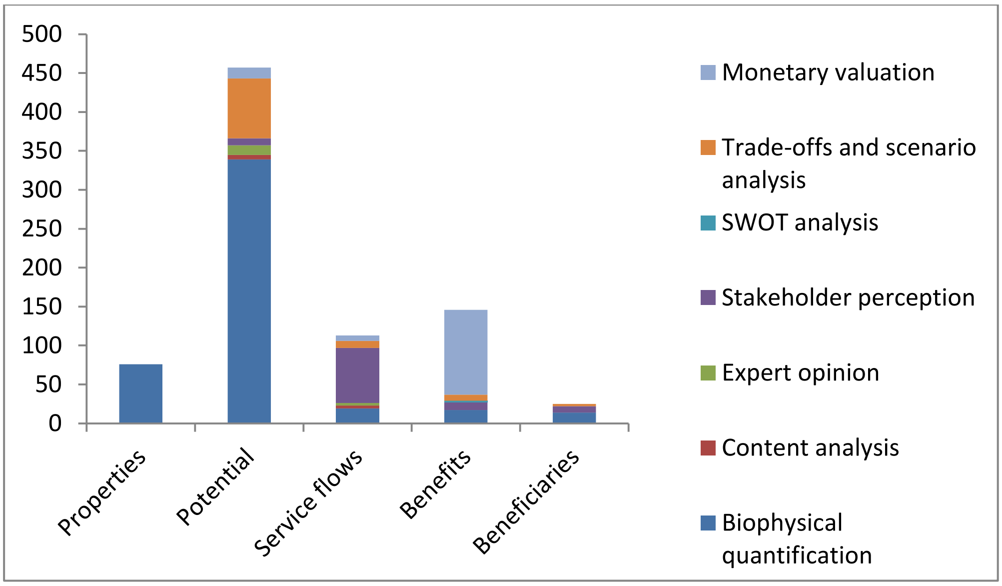

Figure 2.5: Regulating services divided into five components of ecosystem service of (properties, potentials, service flows, benefits and beneficiaries) and methods used to measure each component.

The monetary valuation techniques used to measure the benefits of regulating services are shown in Figure 2.6. Replacement cost was most frequently used followed by the contingent valuation method, service value method and market price method.

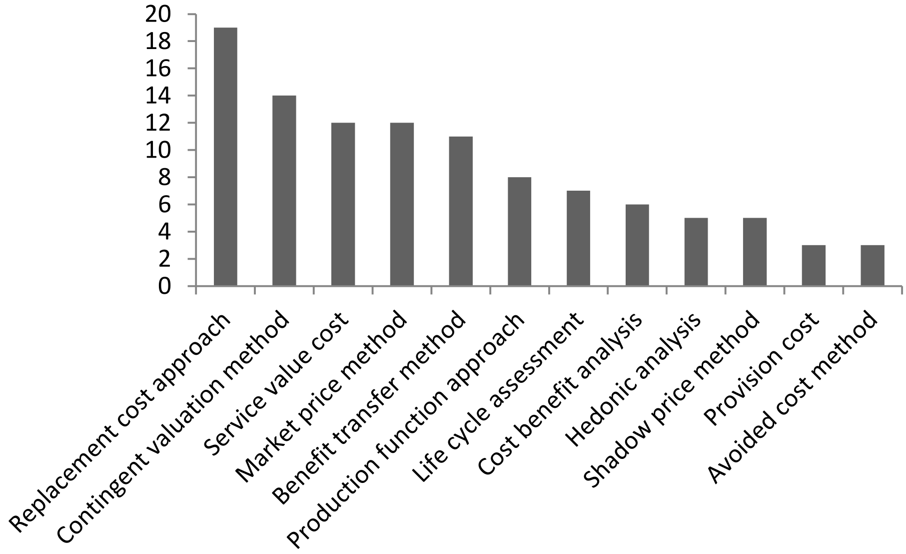

Figure 2.6: Monetary valuation techniques used to value the ecosystem service benefits of regulating services.

2.5 Discussion

The review summarises the advances made in regulating service research since the publication of the Millennium Ecosystem Assessment, more than a decade ago. The quantitative analysis reveals that research aimed at assessing regulating services has increased greatly in the past decade. Our review revealed some clear trends. According to the analysis the most frequently assessed services are those relevant to climate, land use and demographic changes (Evans et al. 2014, Petz et al. 2014). These include climate regulation followed by water flow regulation, erosion regulation, water purification and waste management. The high number of assessments done on climate regulation can be attributed to the relative ease with which carbon storage can be quantified (Osuri et al. 2014, Zhao et al. 2015). The high profile of climate change as an adaptive strategy, policy options such as REDD+ (Matthews et al. 2014), and the work done by the Intergovernmental Panel for Climate Change (IPCC 2012) have also contributed to increased research of the service. Despite their role in ensuring human well-being regulating services of air quality regulation and disease regulation have received less attention. Due to the multiple factors and uncertainties involved in the actual delivery of the air quality regulating service it is still an object of debate (Baró et al. 2014) Insufficient knowledge on the dose-response relationships have also prevented prediction of changes in service flows of air quality regulation (Everard et al. 2013). Non-linear, complex interactions between multiple drivers of change make elucidating the relationship between biodiversity loss and infectious diseases difficult, the specific mechanisms underlying the regulation of diseases is not yet known (Hough 2014).

Most assessments of regulating services were carried out at the patch and regional scale. Yet the supply of most regulating services is influenced by larger, cross-scale processes (Hein et al. 2006, Cumming et al. 2012). Studies assessing regulating services at multiple scales are also very limited (Lesschen et al. 2009, Andersson et al. 2015). Human activities are rapidly changing landscapes which have a direct impact on regulating service provision. Most regulating services assessments are place-based; knowledge on and adequate monitoring of habitats is therefore important for informing land use planning aimed at ensuring sustainable service provision (Iverson et al. 2014). The majority of studies included in the review were not bound to a specific habitat, but rather occurred within a certain geographical region, watershed or conservation area, resulting in the 'mixed' habitat type accounting for the largest in this category. In many of these cases research was done in relation to a management unit to assist with decision making. Following this, the most commonly studied habitat type was that of agricultural ecosystems. Agricultural ecosystems are directly managed by humans to meet human needs (e.g. provisioning services such as food, fibre and fuel) and can significantly impact regulation ecosystem services (Felipe-Lucia et al. 2014, Swinton et al. 2015). Forests were also very well studied as they not only play a key role in influencing climate, but are vital for the provisioning of a number of regulating services such as water flow regulation and erosion regulation (Nunez et al. 2006, Streck and Scholz 2006). More than half of the world's population live in urban areas (UN 2014), yet less than ten percent of research was carried out in urban ecosystems. As human populations continue to concentrate in urban ecosystems, it will become increasingly important that the regulating services(especially air quality regulation , disease regulation, climate and natural hazard regulation) and the ecosystems that provide them are understood and valued by city planners and political decision makers (Bolund and Hunhammar 1999, Depietri et al. 2012). The review shows that very little research has been done on estuarine and coastal and marine habitats, this could be due to multiple factors, which include weak knowledge on these systems and their high levels of land use demands (urban, farming, recreation etc.) conflicting with ecosystem service management and conservation (Barbier et al. 2011, Maes et al. 2012, Pinto et al. 2013). As with many reviews, it was found that the majority of research has been conducted in North America, Europe and Eastern Asia, with fewer studies undertaken in Africa, Central America and the rest of Asia. This is an obvious shortcoming when considering that these latter regions are usually associated with higher reliance on regulating services due to vulnerability to extremes weather events, combined with high levels of inequality, and populations that are highly dependent on local ecosystem services (Mirza 2003, Guo et al. 2010, Egoh et al. 2012).

As with all ecosystem services, regulating ecosystem services have ecological, economic and social dimensions which are deeply connected and interactive; their assessment therefore requires a multi-disciplinary approach (Uy and Shaw 2013, Jones et al. 2016). The majority of studies included in the review were however conducted within a single scholarly discipline, with quantitative analysis the main analysis type used. This may be the linked to the early stage of regulating service research, where single disciplines explore in-depth aspects of the services, but ultimately more integrated and interdisciplinary approaches will be required to link the social and ecological components of regulating services and their connections to human well-being and governance (Armitage et al. 2012, Rohlf 2013).

Similarly much of the focus of this research is on the potential and biophysical supply of regulating services. Ecological methods, remote sensing, geographic information systems and statistical techniques to measure ecosystem service value are popular methods used to quantify regulating service supply (Hao et al. 2012, Yuan et al. 2012). To supplement and extend empirical knowledge on the potential supply of regulating services, expert knowledge (Quijas et al. 2012, Carollo et al. 2013) as well as stakeholder perceptions is increasingly being used. The use of expert knowledge is especially useful in data scarce regions. Understanding the preferences of locals and why they value certain services higher than other can help policy-makers and planning managers make more effective decisions regarding development and conservation (Lamargue et al. 2011, Lindemann-Matthies et al. 2014). The outputs of a stakeholder perception analysis can be linked to broader landscape level measures through mapping (Raymond et al. 2008), or assessments of ecosystem trade-offs (Martin-Lopez et al. 2012).

From the review the most commonly used approach for assessing benefits has been monetary valuation. Due to the invisible nature of regulating services surrogate market valuation methods are often implemented to estimate the value of regulating services (Kumar and Wood 2010). The most commonly applied approach has been replacement cost in which the cost of replacing the service with that of man-made infrastructure is estimated. This approach is especially popular for the valuation of water purification and waste treatment regulation (Cruz et al. 2011, Lin et al. 2011). Contingent valuation which involves directly surveying people to elicit their willingness to pay or accept payment for a change in ecosystem services was often used to estimate the value of climate regulation and natural hazard regulation (Ingraham and Gilliland 2008, Kakuru et al. 2013). Market-price approaches utilising prices from actual markets was mostly used to value climate and water flow regulation (Lin et al. 2011, Ghaley et al. 2014). Although less common, non-monetary techniques such as rapid rural appraisal (Pereira et al. 2005), biophysical quantification (Klatt et al. 2013), trade-offs and scenario analysis (German et al. 2010, Meehan et al. 2013) were also successfully used to assess the benefits received from regulating services.

Despite the need to link supply with demand services, there have been very few studies aimed at quantifying ecosystem service demand. The most common approach for measuring demand has been the use of biophysical quantification (Bagstad et al. 2013, Stürck et al. 2014, Castro et al. 2014), with a few studies using stakeholder perception, trade-offs and scenario analysis (Castro et al. 2014). The lack of research can be attributed to the fact that demand for ecosystem services is driven by complex interactions between socio-economic conditions, demographics and cultural norms (Villamagna et al. 2013) for which the necessary data and approaches may not yet be available. Studies focused on quantifying regulating services will benefit from more integrated social-ecological systems approaches which incorporates both biophysical and human dimensions (Fischer et al. 2015)

2.5.1 Gaps and recommendations

Results of the quantitative review suggest that there have been advances since the publication of the Millennium Ecosystem Assessment, for many services and many regions. Regulating services however remain valuable and declining (Lant et al. 2008, Santos-Martin et al. 2013). Key gaps related to the wide diversity of regulating services, their links to human well-being and their cross scale and complex nature suggests that the full potential of regulating services to inform better management and sustainable developments has not yet been realised. Research on regulating services will benefit from increased multi-disciplinary research using social-ecological system approaches. As well as increased research efforts aimed at understanding the complex, but vital regulating services of air quality regulation and disease regulation.

2.6 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field*. *Ecosystem*

Management Series no. 9 .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward.

2015a. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing

ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and*

Resources 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral*

Research 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O'Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth*

Surface Processes and Landforms 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland’s valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

Garen, D. C., and D. S. Moore. 2005. "Curve number hydrology in water quality modeling: Uses, abuses, and future directions," - Reply to discussion. *Journal of the American Water Resources Association* 41(6):1493–1494.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in

integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D.

Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors).

Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale

environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature’s benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for

a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services.

Progress in Physical Geography 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the

case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity* 12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*

8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O’Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O’Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of*

Disaster Risk Reduction 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*.

Garden. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance.

Ecological Modelling 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth 's climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-

Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E. 2008. *South African atlas of climatology and agrohydrology*. Pretoria.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the "regulating" services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A*

multi-stakeholder approach to targeted intervention in selected municipalities. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International …*.

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB*.

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in

the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems : A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 3
An integrated landscape perspective for managing floodwaters

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3.1 Abstract

Increases in extreme weather events are expected to lead to increases in the occurrence of floods, putting communities and infrastructure in flood prone areas at risk. Assessment of how biophysical features combine and interact with one another at the watershed scale to generate floods can provide important information for improved flood management and the development of mitigation measures. These assessments are usually data and methodologically demanding, precluding many areas from such studies. Here we adapt and explore an existing decision support tool, SCIMAP, using globally available elevation, land cover and soils data to provide a practical and informative approach for identifying flood receiving areas at a watershed scale. Outputs from a case study application of 18 adjacent watersheds along the Southern Cape Coast of South Africa include a surface flow connectivity index; flood generation potential map; stream power index and a flood receiving areas map. The model results show that high hydrologic connectivity between the small, steep watersheds and short river reaches make the Garden route watersheds highly responsive to rainfall events. Flood receiving areas are concentrated in the lower lying areas surrounding waterbodies and floodplains and settlements located near rivers. These outputs highlight how the combined effect of natural and anthropogenic factors can aggravate or attenuate a flood event, adding valuable insights into flood generation and how it can be managed, especially in under resourced areas.

Keywords: Flood regulation; Prioritisation; Flood management; Conceptual Models; Ecosystem services, Geomorphology

3.2 Introduction

The occurrence of flood events has increased globally over the last three decades with climate change effects expected to increase the frequency, intensity, duration and spatial extent of large floods in some regions (Poff 2002, Palmer et al. 2009, Death et al. 2015). Floods are complex natural phenomena brought about by interactions and feedbacks between climate inputs and landscape characteristics that occur over a wide range of space and time scales (Band et al. 2012, Pattison and Lane 2012). "A hazard is an event or physical condition that has the potential to cause fatalities, property and infrastructure damage, agricultural loss and damage to the environment" (Bahauddin and Uddin 2012). Due to the unpredictable nature of floods, the degree of vulnerability to damage from flood hazards can vary. In order to better manage, understand and protect against floods it is therefore important to identify and locate the flood hazard areas in a watershed.

Traditional flood management approaches have focused on river training through the construction of embankments and the raising of dams, to reduce the frequency of flooding (Brown and Damery 2002, Vis et al. 2003). Over time there has been a realisation that successful management of flood impact requires a systemic understanding of both structural and functional dynamics of watersheds (Vigerstol and Aukema 2011, Syrbe and Walz 2012). In this expanded approach, the adverse impacts of flooding are reduced through enhancing and conserving natural ecosystem flood regulation capacity, land use adaptation, and flood resilience strategies (Vis et al. 2003, Lundy and Wade 2011, Barbedo et al. 2014). Intact landscapes are able to capture and store water from rain storms and slowly release it in a process known as flood regulation, one of the benefits or services humans receive from nature (MA 2003). Natural ecosystem features and processes can, depending on rainfall intensity, moderate flood impacts or, in some cases, even prevent flooding (Guo et al. 2001, Brauman et al. 2007, Brocca et al. 2008). The capacity of a landscape to store water is dependent on the underlying geological and climatic characteristics, its land use and how those uses are managed (Burke et al. 1991, Fitzjohn et al. 1998, Puigdefábregas 2005). Overland flows are largely controlled by characteristics of the watershed, variation in the spatial arrangement, slope, topography, soil depth and roughness of soil surface features (Darboux et al. 2002, Terrado et al. 2014). Hortonian or infiltration excess overland flow (HOF) occurs when the rainfall rate exceeds the surface infiltration capacity. This flow is associated with a low infiltration capacity and/or steep slopes in combination with high rainfall intensities that exceeds the infiltration capacity (Schüler 2006). Saturation excess overland flow is produced when the absorptive capacity of the soil is exceeded. It usually occurs on sites with impermeable clay or loamy layers and shallow soils (Schüler 2006). Soil storage capacity refers to the maximum amount of water a soil can retain within soil pores and voids and is related to soil structure, porosity, drainage depth of soil profile class, and depth of the water table (Hümann et al. 2011). The dynamics of runoff generation are closely linked to the hydrological connectivity between the surrounding hillslopes and the river channel network (Tetzlaff et al. 2007, Nieber and Sidle 2010).

These multiple features, and their interactions and dynamics, make it challenging to quantify and assess the capacity of landscapes to regulate floods. Various approaches to understanding the spatial variability in flood regulation have been developed to advance knowledge, inform management and design mitigation efforts. Approaches range from modelling empirical relationships to detailed, process-based models for predicting hydrological responses (Kim et al. 2012, Biscarini et al. 2013). While process-based models are able to provide time-series inundation information about the onset, duration and passing of a hazard event, they require considerable expertise in model design and parameterisation, data input and management of large datasets. The resulting outputs can also be difficult to interpret without expertise in modelling fundamentals and specialised software (Zerger and Wealands 2004, Hassel 2012). This is particularly so in developing countries where data for such models and the capacity to interpret model outputs are limited. Often simpler watershed scale models are able to model watershed processes with much less predictive uncertainty (Sivapalan 2005, Savenije 2010). A possible middle ground may be the use of parsimonious models that represent the simplest approach, but nonetheless allows for the exploration of the organising principles that underlie the heterogeneity and complexity of watershed processes (McDonnell et al. 2007).

A number of studies have used the concept of critical source areas to model how fine sediments, organic matter and nutrients are transported by water from the source to the waterbody (i.e. delivered) (Agostinho et al. 2009, Reaney et al. 2011, Pirard 2012) by modelling hydrological connectivity, particularly those focusing on the likelihood of delivery and how it varies spatially (Beven et al. 2005, Lane et al. 2006, 2009). Because non-point source (diffuse) pollution models are designed to identify areas which are most likely to generate surface runoff, either by infiltration excess or saturation excess, which allows for rapid responses to rainfall, they capture the spatial distribution in the strength of a key flood generation process (Moore et al. 1991, Hahn et al. 2014). They may, therefore, offer a potential avenue for representing the spatial patterns in the potential source and delivery areas for floodwater using widely available data on topography and land cover (Lane et al. 2003). The use of these models also allows for a shift from local scale flood hazard assessment to assessments which focus on the scale at which floods are generated and propagated – the watershed scale. This is also the scale at which management agencies operate and decision making can affect flood management. Although studies often treat water and sediment separately, there is no basis for doing so as the controls (i.e. the hydraulic and sediment transport processes) are both determined by the channel network (Downs and Prienstnall 2003, Croke et al. 2013). In fact, more integrated and interlinked approaches may be the key for a better understanding and management of hydrological hazards. In order to explore the potential of non-point source pollution models in capturing the role of landscapes in regulating floods, this study test whether the Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) model can be adapted to identify flood source and receiving areas to support flood management.

3.3 Methods

3.3.1 The SCIMAP model

There are a number of models which have been developed to identify critical source areas (CSA's) in a watershed. The Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP), a decision support tool developed by the Durham and Lancaster Universities along with the British Environment Agency (http://www.scimap.org.uk/) was chosen because it uses readily available datasets and can be used at any scale. The main aims of the model are to identify source areas and pathways of poor water quality and sediment erosion using the concept of hydrological connectivity (Reaney et al. 2011, Milledge et al. 2012). As it captures the key hydrological processes involved in flood generation from surface runoff, the modelling framework used in SCIMAP could be adapted and used to identify flood receiving areas. Additional outputs from the model can be used to better understand and predict watershed hydrological response and include (a) a network index which shows the flow pathways which connects the upland zone (hillslope) to a drainage line (river); (b) a runoff generating potential map which shows the relative runoff generation and connectivity potential for each location in the watershed, (c) a stream power index in which slope and surface flow connectivity is extracted from a DEM to produce a relative steam power map which represents the rate of flow (velocity) and, thus, the energy available to perform geomorphic work as water travels downstream.

3.3.2 Model inputs

The model inputs consist of: (1) topographic data of appropriate spatial resolution and vertical precision; (2) land-cover data; (3) design rainfall data and (4) soils data. For topographic data a 30m Digital Elevation Model (DEM) with a planimetric accuracy of 15.24 metres was used (Chief Directorate Surveys and Mapping 2002). The national land-cover (NLC) 2000 data for South Africa, Lesotho and Swaziland derived from satellite images and field verification was used to obtain land-cover data (Van den Berg et al. 2008). To account for extreme rainfall events, design rainfall data for a 50 year return period were taken from the South African Atlas of Climatology and Agrohydrology (Schulze and Smithers 2007). Design rainfall is a theoretical storm event based on rainfall intensities (using historical rainfall data) associated with a frequency of occurrence and a set duration (Smithers and Schulze 2002). Hydrologic soil type data was inferred from soil texture data obtained from the Soils and Terrain Digital Terrain Digital Database (SOTER) for South Africa (Dijkshoorn 2003). Model inputs were interpolated onto the topographic data resolution of 30m via a nearest neighbour algorithm using ARCGIS 10.3 and Spatial Analyst (Environmental Systems Research Institute 2015).

3.3.3 Model application

The SCIMAP modelling framework consists of five main steps. In this paper the framework is adapted from measuring fine sediment risk (Reaney, 2011), to measuring flood receiving areas. In step one, the flood generation risk for each land cover class is determined by multiplying the energy available to generate runoff by the resistance to runoff generation. In the model the energy available to generate runoff is assumed to be positively related to the upslope contributing area and the local slope which is both derived from the 30m DEM (Reaney, 2011). To measure the resistance to runoff generated, we used the Natural Resources Conservation Services Runoff Curve Number (NRCS) was used to infer a runoff weighting upon each land cover class. The NRCS runoff curve number (CN) was selected as it is used as a core component of many of the more sophisticated hydrologic models, yet requires only readily available data (Du et al. 2012, Grimaldi et al. 2013). It is an index developed by the United States Department of Agriculture in 1972 and is a function of land cover type and hydrologic soil group (USDA 1986). It is a numerical description (0-100) of the impermeability of the land in a watershed. The runoff curve number provides a first approximation of the potential for surface runoff, with greater curve numbers indicating a greater proportion of surface runoff and consequently lower infiltration, and smaller curve numbers indicating low runoff and consequently higher infiltration (Laura et al. 2011). The runoff curve number (CN) is a dimensionless number, which is reasonably robust, and therefore, lends itself to be incorporated into the SCIMAP framework. The use of run off curve numbers is controversial as it has been used in the past without consideration of the limitation of the approach (Garen and Moore 2005). Here the approach is used at a watershed scale to serve as a weighting based on the land cover and soil type. For the generation of the curve numbers, data inputs comprises a soil map of soil types and textures as well as a land cover map. The soil map was clipped to the study area using ArcGIS Desktop 10.3. Based on this map, hydrological soil groups were identified depending on soil texture and permeability. Soils were classified into four hydrological soil groups (A, B, C, and D) (Table 3.1).

Table 3.1: Hydrologic soil groups identified from soil textures.

Soil group	Nature/description	Soil texture
A	Well drained (high infiltration).	Sand, loamy sand, or sandy loam.
B	Moderate to well drained (moderate infiltration).	Silt loam or loam.
C	Poor to moderately well drained (low infiltration).	Sandy clay loam.
D	Poorly drained very low infiltration.	Clay loam, silty clay loam, sandy clay, silty clay or clay.

The resulting hydrological soils group map was intersected with the National Land Cover (NLC) 2000 of South Africa, to form a land cover hydrological soils group map using ArcGIS Desktop 10.3. The curve number for each polygon was determined using an existing CN database created by (Thomas 2015) using the NLC 2000 of South-Africa. For the purposes of the SCIMAP model, curve numbers were rescaled from 0-100 to 0-1 by dividing by 100. The study area is characterised by predominantly well drained type A sandy soils and poorly drained low infiltration type D soils, CN curve numbers were therefore only calculated for these two soil groups (Table 3.2). In step two the connection probability is determined based on a network index similar to the topographic wetness index of (Beven and Kirkby 1979)Bevin and Kirkby, (1979). The network index is based on the assumption that as the watershed wets up, it becomes increasingly connected as points that were previously disconnected start to generate and transmit runoff, connecting the upslope areas of the watershed to the river channel (Lane, 2009). At this point each location in the watershed has a flood generation risk and a connection probability, which in step 3 are multiplied together to produce the runoff generating potential. In step 4 the runoff generating potential is routed through to the river network using the flow pathways previously generated from the DEM to produce a loading risk. In the fifth and final step the upslope contributing area derived from rainfall and topographic data is added to the loading risk to produce a flood risk concentration. The results represent a relative ranking of flood receiving areas.

Table 3.2: Runoff curve numbers assigned to land cover and soil hydrological groups

Land cover	NRCS Curve Numbers	
	Hydrological Soil Group A	**Hydrological Soil Group D**
Bare Rock and Soil (natural)	0.77	0.94
Cultivated, permanent, commercial, irrigated	0.51	0.9
Cultivated, temporary, commercial, dryland	0.67	-
Cultivated, temporary, commercial, irrigated	0.74	0.9
Forest (indigenous)	0.3	0.77
Forest Plantations (Acacia spp)	-	0.77
Forest Plantations (clearfelled)	84	0.82
Forest Plantations (Other / mixed spp)	0.3	0.77
Forest Plantations (Pine spp)	0.3	0.77
Improved Grassland	0.39	0.8
Mines & Quarries (mine tailings, waste dumps)	-	0.84
Shrubland and Low Fynbos	0.39	0.8
Thicket, Bushland, Bush Clumps, High Fynbos	0.36	0.79
Urban / Built-up (residential)	0.81	0.93
Urban / Built-up (residential, flatland)	0.61	-
Urban / Built-up (residential, formal suburbs)	0.54	0.85
Urban / Built-up (residential, formal township)	0.77	0.92
Urban / Built-up (residential, informal squatter camp)	0.89	0.95
Urban / Built-up (residential, informal township)	0.81	0.93
Urban / Built-up (rural cluster)	0.81	0.93
Urban / Built-up (smallholdings, thicket, bushland)	-	0.84
Urban / Built-up, (commercial, education, health, IT)	0.81	-
Urban / Built-up, (commercial, mercantile)	0.95	0.98
Urban / Built-up, (industrial / transport : heavy)	0.89	0.95
Urban / Built-up, (industrial / transport : light)	0.77	0.92
Waterbodies	1	1
Wetlands	1	1

Model results were exported to GIS where thematic maps where produced for model outputs. The stream power index and flood receiving area maps classified into categories based on the degree of hazard (ranging from very low to very high) using the standard deviation classification (Environmental Systems Research Institute 2015). This classification was chosen as it provides relative stream power and flood receiving area values, which allows for comparisons between locations and identification of problematic areas. Outputs were further analysed by overlaying the final thematic maps with a river networks, wetlands, waterbodies and a settlements layer in Arc GIS desktop 10.3.

3.3.4 Model verification

One of the constraints to the verification of results of the SCIMAP model was the lack of credible and sufficient flood records available for the study area. To verify the spatial distribution of the model results, the flood receiving areas map was compared with publically recorded flood records obtained from a workshop organised by the Western Cape Department of local government, sub-directorate: Risk Reduction Planning. Workshop participants consisted out of key stakeholders well acquainted with the area and its hydrological regime. At the workshop participants were asked to identify areas on a map that are known to be inundated during flood events which occurred in recent years. This information was then captured and spatially presented as data points using GIS.

3.3.5 Case study watersheds

The approach was applied to eighteen adjacent study watersheds in the Southern Cape of South Africa. The study watersheds forms part of what is known as the “Garden Route”, so called due to its rich biodiversity and pristine natural landscape and occupies an area of 3008 km^2 (Fig. 3.1). In the last decade the watersheds of the Garden Route has experienced an increase in the frequency and occurrence of torrential rain associated with winter cut-off lows (RADAR 2010). Extremely heavy rainfall over the area’s steep watersheds often results in high run-off, short delay flash floods, which have devastating effects on downstream watersheds (Mélice and Reason 2007, Tempelhoff et al. 2009). Burgeoning development and urbanisation impacts have led to alteration in runoff, leading to higher and earlier flood peaks, and greater propensity for erosion and sediment transfer (Marker and Holmes 2005). Disturbance of the natural vegetation has also allowed alien *Acacia spp*. invasion particularly along mayor valleys (Baard and Kraaij 2014). These invasive plants are easily ripped out by floodwaters forming large woody debris that can cause blockage or strike and damage infrastructure (Le Maitre et al. 2014).

Daily temperatures in the region average between 14.6 and 20.7 °C, with annual precipitation averaging between 700 and 1200mm per annum. The landscape is characterized by largely rocky narrow watersheds, with shallow soils, steep slopes and deeply incised river valleys which terminate in estuaries and form coastal lagoons in places (Marker 2003). The estuaries and lake systems are a special feature of the Garden Route and are important both to the ecology and the tourism centred economy of the region (Turpie et al. 2002, Maree 2010, Russell 2013).

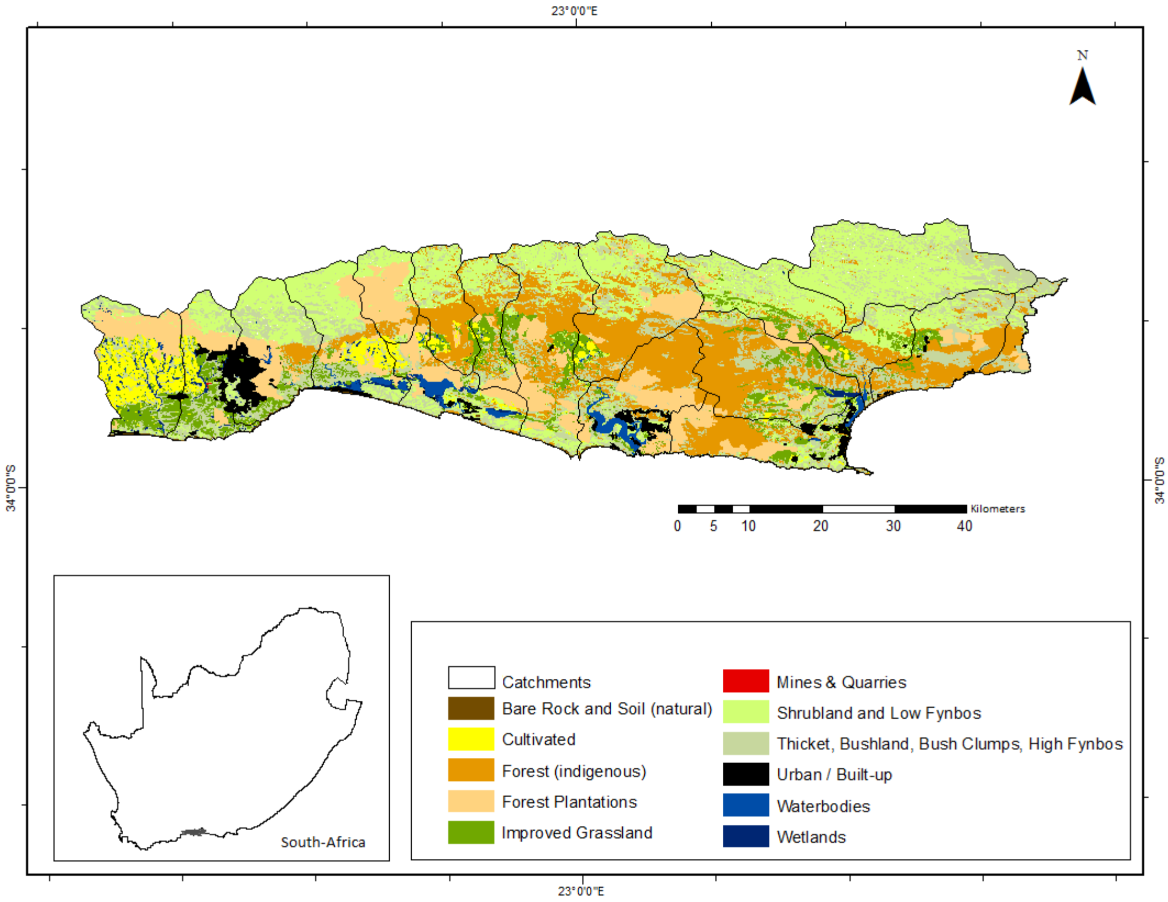

Figure 3.1: Map of selected Garden Route catchments, South Africa showing the main land cover classes and catchment boundaries.

The geomorphological characteristics of the Garden Route watersheds play a major role in how floods are generated (Marker 2003, Marker and Holmes 2005). To account for the heterogeneity of the landscape and to facilitate interpretation, the study area was stratified into the geomorphic provinces of Partridge et al., (2010). According to Dollar et al. (2007) "Geomorphic provinces are areas of similar relief, climate, lithological assemblages or fluvial evolutionary patterns, which impose broad constraints on lower levels of organisation, e.g. drainage basins, macro reaches and channel types". Using the classification system of Partridge et al., (2010) the study area can be divided into three distinct provinces namely: the Central Cape Fold Mountains; the Southern Coastal Platform and the Southern Coastal Lowlands (Fig. 3.2).

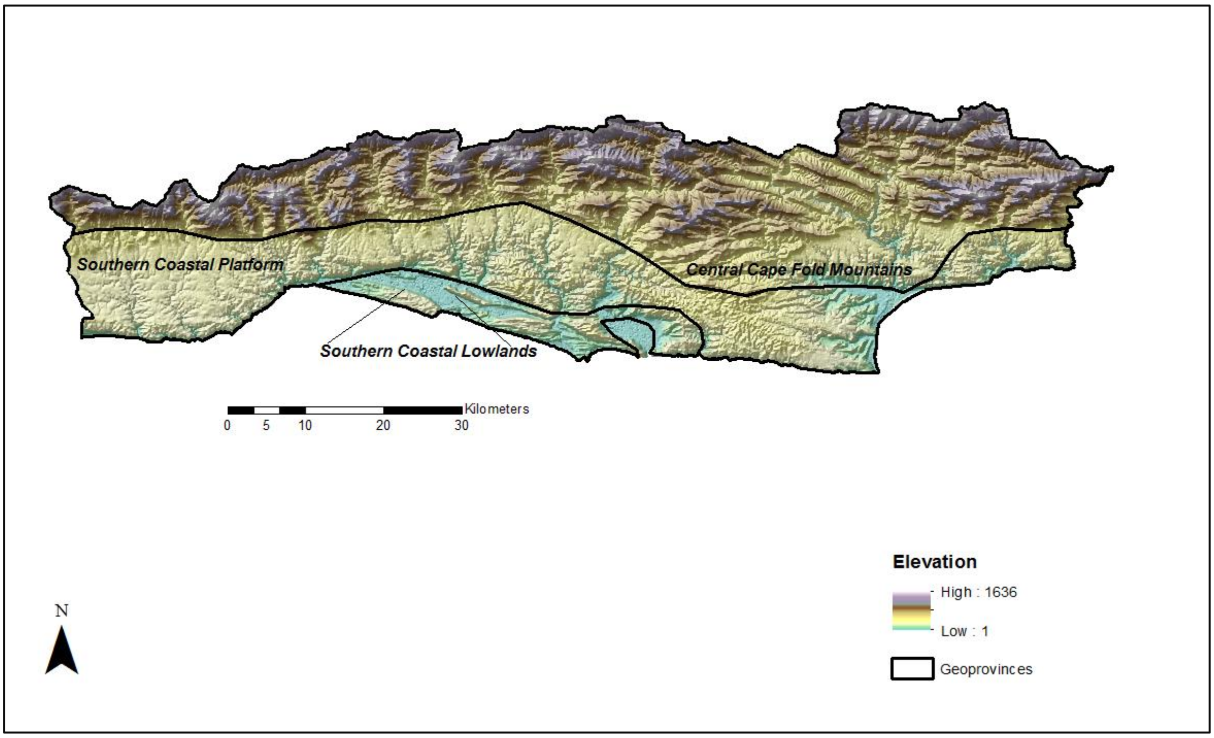

Figure 3.2: Map of the three geomorphic provinces as taken from (Partridge et al. 2010).

3.4 Results

3.4.1 Main derivatives of the DEM

Figure 3.3 shows the main derivatives of the DEM and land cover map used in the calculation of the point scale runoff generating areas. The study area has relatively high hydrological connectivity across all watersheds (Fig. 3.3(a)). From the map 1% of the catchment has a hydrological connectivity of -1 which is restricted to the upper mountain catchment north east of the study area. Areas with a hydrological connectivity between -0.9-0.36 make up only 0.35% of the catchment area and are concentrated along the coastal boundary. Areas with a hydrological connectivity between 0.38 and 0.8 make up 10% of the study area and occur in the upper mountainous areas of the Central Cape Fold Mountains characterised by high elevation. Areas with a hydrological connectivity between 0.82 and 0.93 make up 16% of the catchment area and are located predominantly in the upper mountainous catchments of the Central Cape Fold Mountains, but also in the lower parts of the Southern Coastal Platform characterised by steeper slopes. Areas with a hydrological connectivity between 0.94 and 1 make up 71% of the study area and are located in the Southern Coastal Platform and Southern Coastal lowlands characterised by lower elevation. From the flood risk weighting (Fig. 3.3(b)) very high flood risk was predicted for the waterbodies of the southern coastal lowlands. Areas of high flood risk cover 13% of the study area and consist predominantly of cultivated land and urban/built up areas on poorly drained type D hydrological soils in the southern coastal platform. Areas of low flood risk occur in indigenous forest areas and forest plantations, and are located on predominantly sandy textured type A soils. Thicket, shrubland and low fynbos as well as grassland areas of predominantly poorly drained type D soils are classified as having medium flood risk. The stream power index (Fig. 3.3(c)) indicates high stream power values in both the upper and middle reaches where slopes are steep.

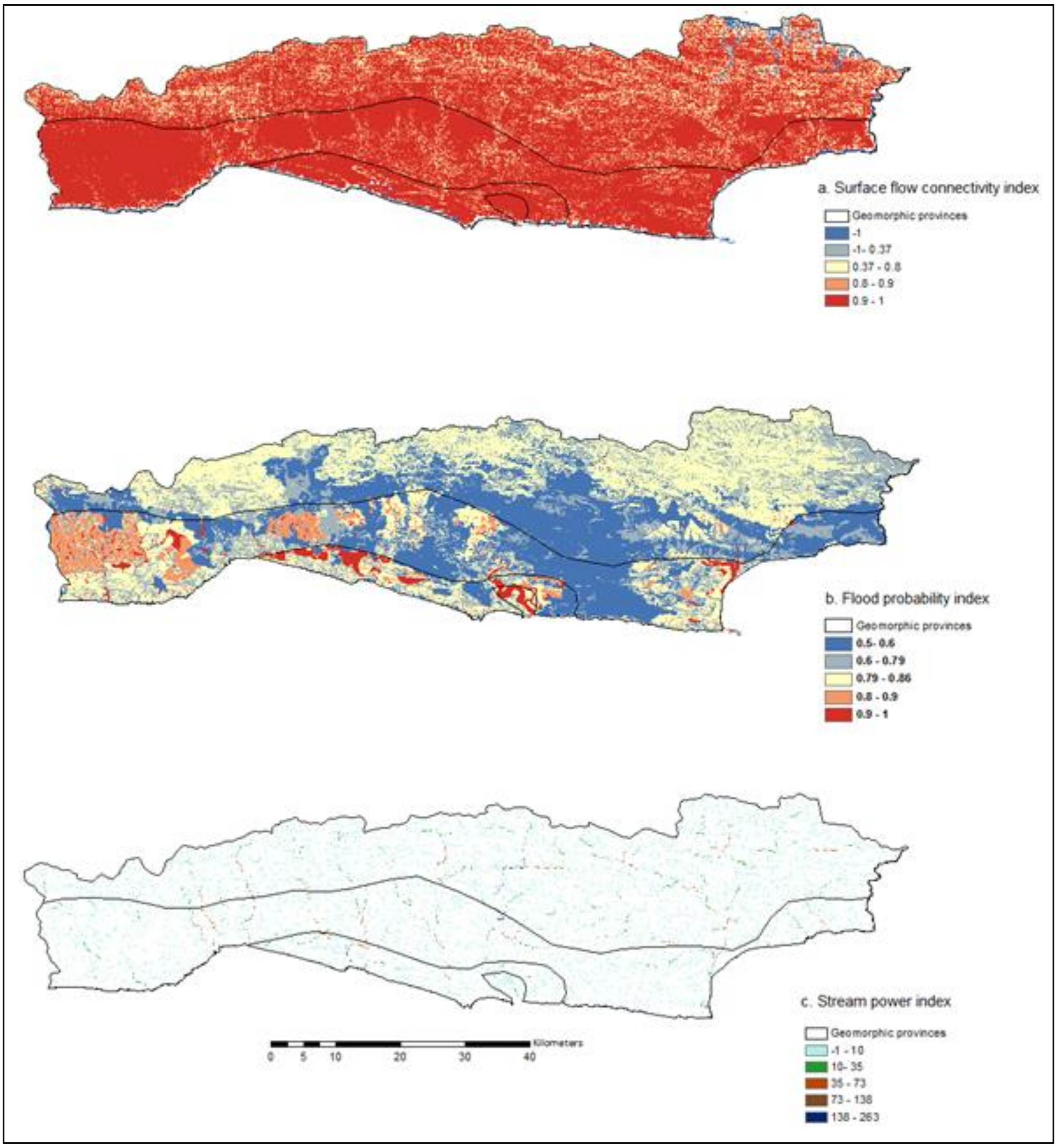

Figure 3.3: Shows (a) The network index which is used to determine the surface flow connections. (b) The predicted spatial pattern of the flood generation probability as predicted by the CN number. (c) the distribution of the stream power.

The runoff generation potential map (Fig. 3.4) shows that cultivated and urban/built up areas found in the Southern Coastal Lowlands have the highest runoff generating potential. High runoff generating areas are located predominantly in the steep upper watersheds of the Central Cape Fold Mountains. Runoff generated on the steep upper watersheds areas can either infiltrate or connect with other runoff generating areas such as the riparian areas on the Coastal Platform and the lower reaches of the watershed along the coast. Areas with low to medium runoff potential are areas where runoff is infiltrated or attenuated during rainfall events. According to the results the waterbodies and wetlands of the study area have the lowest runoff generating potential and therefore have the capacity to attenuate floodwaters during a flood event. Natural forest and forest plantations located on the slopes of the Central Cape Fold Mountains, as well as the lower lying areas of the Southern coastal platform, also show low runoff generating potential.

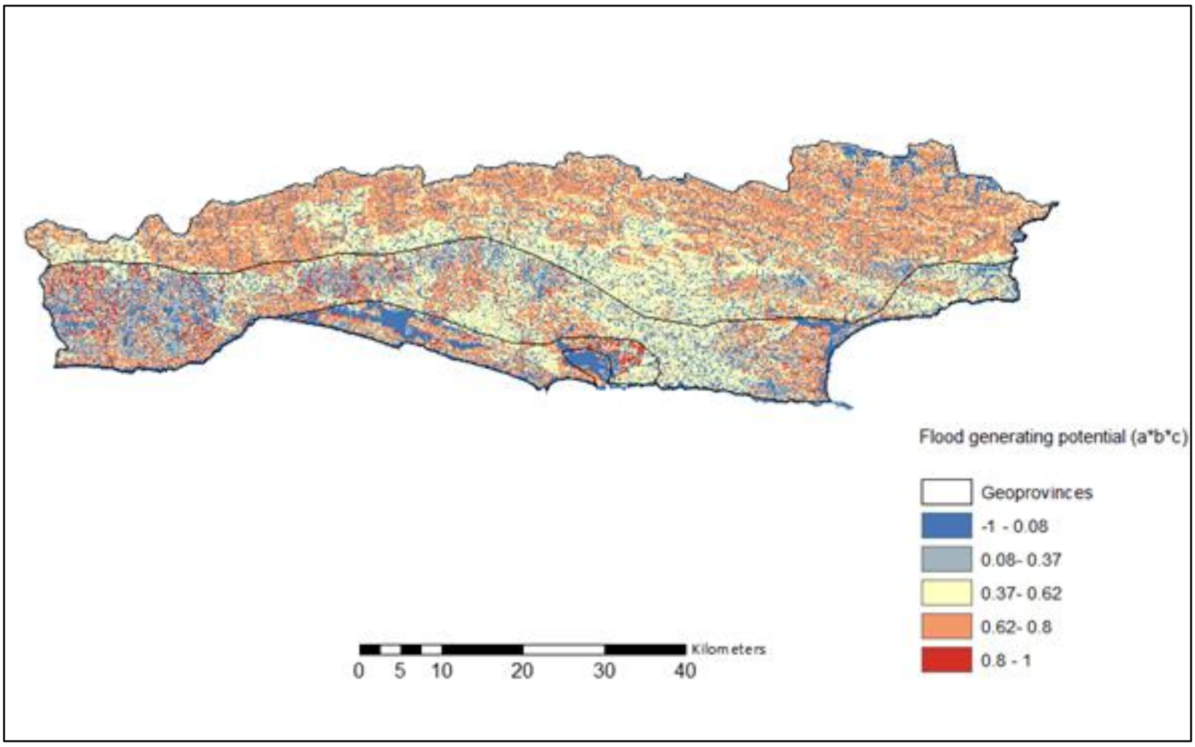

Figure 3.4: Shows the runoff generating potential map which is the product of the convolution of the source area analysis with the connectivity analysis.

The model outputs are integrated though to the drainage network, to produce the total stream power map (Fig. 3.5 (a)). This map shows that the majority of the short steep rivers located in the Garden Route watersheds display high stream power values. The flood receiving areas map (Fig. 3.5 (b)) shows that very high flood receiving areas cover approximately 27% of the study area and are located predominantly in the eastern, more mountainous parts of the watershed as well as in the lower lying areas of the Southern Coastal Lowland. Medium to low flood receiving areas cover 72% of the study area and are located in the upper watersheds of the Central Cape Fold Mountain province.

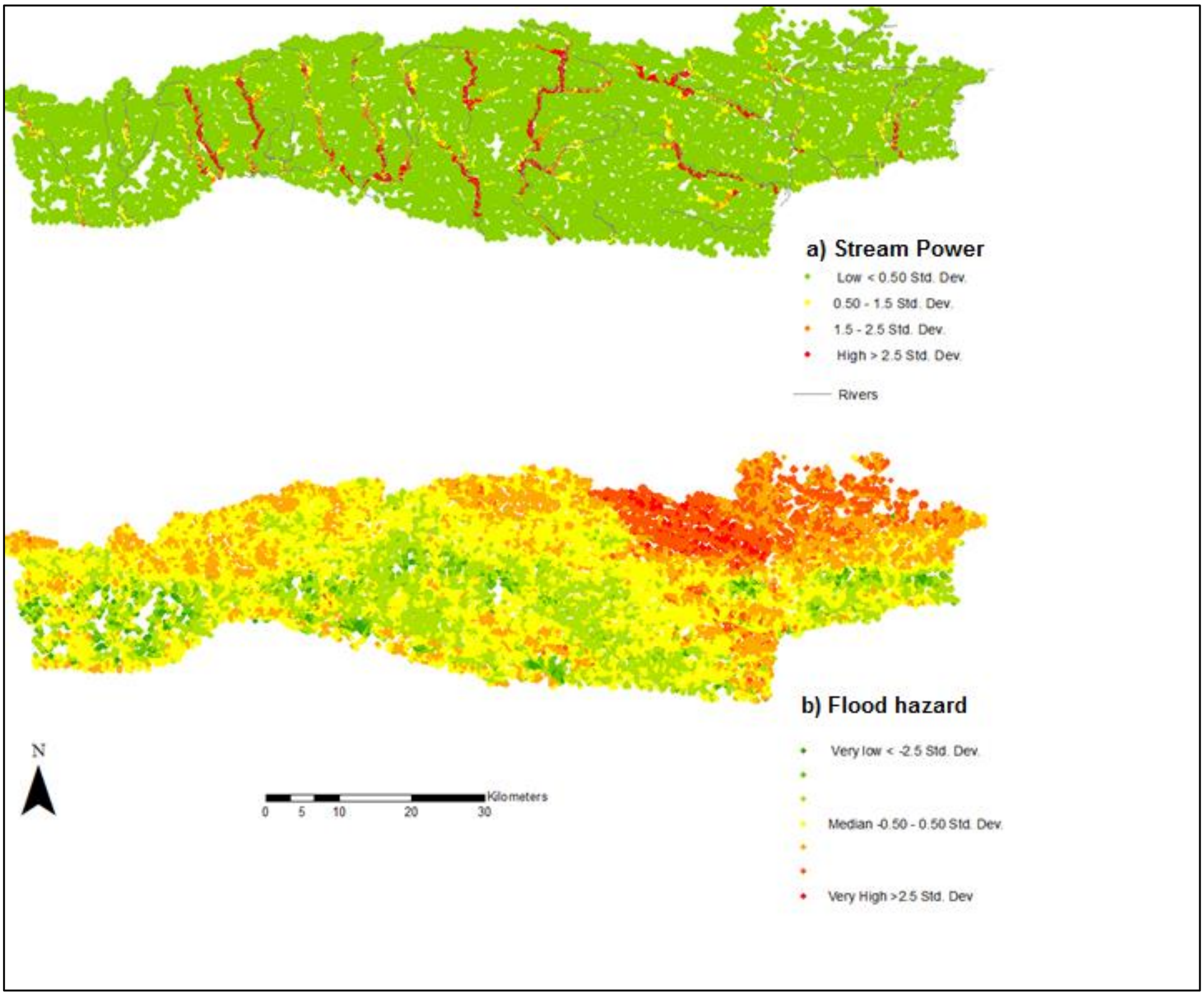

Figure 3.5: The stream power map (a) which is a convolution of stream power index, connectivity, and precipitation (b) the cumulative runoff potential weighted by precipitation, to produce the flood receiving areas.

3.4.2 Model verification

When model outputs were overlain with the public flood records, sixty percent of the recorded flooded points overlapped with areas identified as very high to high flood receiving area areas, thirty-three percent overlapped with medium flood receiving areas while 6 percent overlapped with low flood receiving areas (Fig. 3.6).

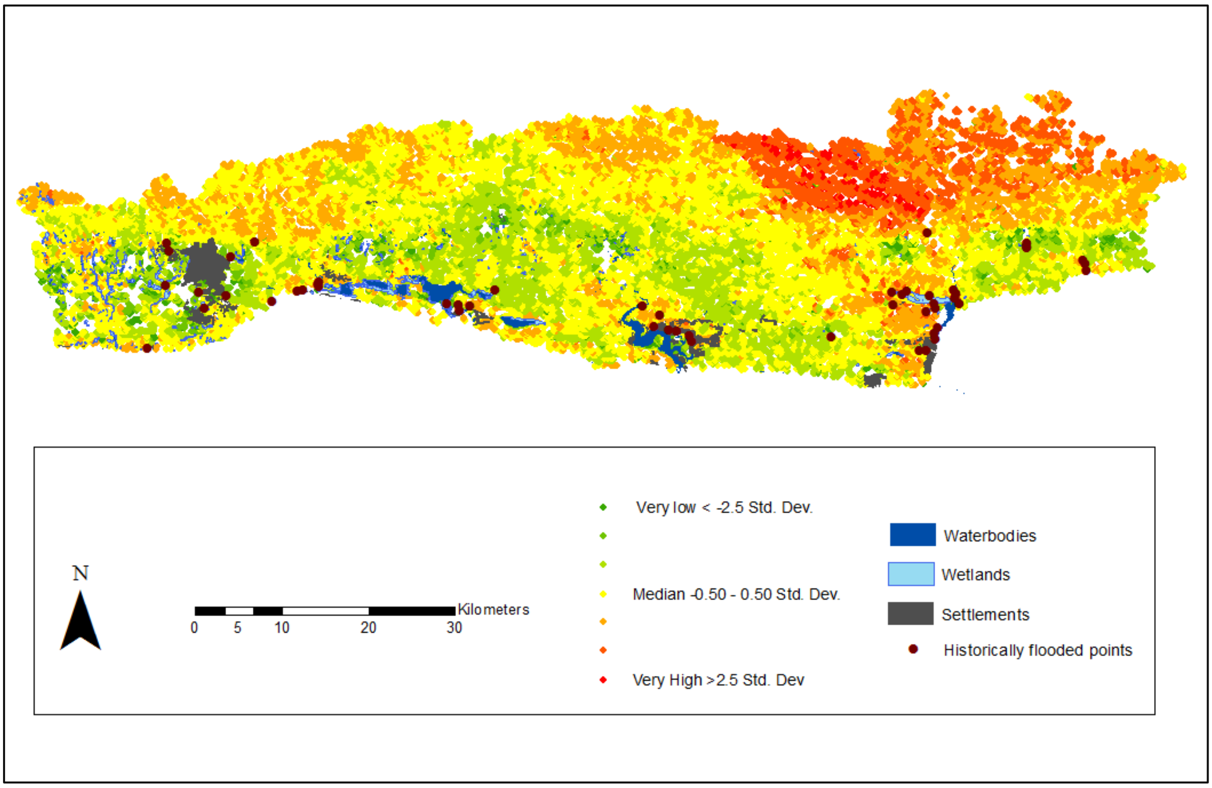

Figure 3.6: The flood hazard map showing the settlements of the study area and recorded points of historical inundations.

3.5 Discussion

This study investigates on the use of the SCIMAP model, for identifying spatial patterns in the potential runoff generating and receiving areas for floodwater. The adapted model framework allows, not only for a clear pattern of spatially concentrated flood receiving areas, but also shows how underlying factors of hydrological connectivity, stream power and land cover combine to drive flood generation. The outputs provide a means for users to identify areas where conservation efforts should be concentrated in order to maintain flood regulation capacity as well as areas where flood mitigation strategies are most needed.

3.5.1 Adapting the SCIMAP model for the assessment of flood receiving areas

By incorporating the Natural Resources Conservation Service (NRCS) runoff curve number (CN) method, the use of the SCIMAP model in a flood hazard context could be investigated. The CN number has been widely used in areas which lack sufficient historical records and detailed runoff information, and has been integrated into many hydrologic; erosion and water-quality models to predict direct surface runoff (Grimaldi et al. 2013, Mohammad and Adamowski 2015). In the SCIMAP model the runoff curve number (CN) serves as a static index, reflecting the infiltration capacity of the different land cover types. Because the runoff curves number (CN) is a dimensionless number it could be incorporated into the SCIMAP framework with relative ease.

3.5.2 Drivers of flood generation in the Garden Route catchments

The areas identified as runoff generating areas by the SCIMAP model are consistent with dominant physical processes previously proposed for hydrological landscapes (Winter 2001, Savenije 2010). The slopes of the upper mountain watersheds are characterised by high relief and low permeability and are the biggest contributors of flood waters in the Garden Route watersheds. The model also identified riparian areas on the coastal platform and areas surrounding waterbodies in the coastal lowlands as potential runoff generating areas. These lower lying riparian areas are characterised by shallow water tables and low storage capacity are often responsible for the early flood response through saturation overland flow, but due to their limited size and moderate slope are not the largest contributors of runoff in the watershed (Savenije 2010). The flood regulating capacities of the Garden Route Watersheds are greatly influenced by the land use type, but are also dependent on landscape position. Areas identified as having low runoff generating potential are the wetlands and waterbodies on the lower lying coastal platform as well as the forested areas on the hillslopes. These areas play an important role in storing water or routing it more slowly through subsurface routes during rainfall events. Land management activities in these areas should be carefully evaluated in order to prevent environmental degradation and ensure continued delivery of the flood regulation service.

Research done by Song et al. (2014) and Vocal Ferencevic & Ashmore (2012) shows that stream power maps can provides further insights into river behaviour and flood development for improved flood management. Several of the river reaches in the Garden Route watersheds has been identified as having high stream power values. In these reaches fast moving water can mobilise sediment or large woody debris, which may dislodge vegetation and strike and damage infrastructure or clog up the river channel (Bendix 1999). As with many coastal plain rivers, the lower coastal regions of the Garden Route watersheds contain areas of ecologically and economically valuable wetlands, and estuaries which are vulnerable to river floods, subsidence and other coastal plain dynamics (Song et. al. 2014). Changes in land cover such as the conversion of forests into agricultural land and pastures can result in increased sediment transport rates during flood events (Kron, 2005). By monitoring downstream changes in land cover and areas of high stream power, problem areas can be prioritised to reduce flood impacts.

3.5.3 Flood receiving areas of the Garden Route catchment

The final output of the SCIMAP model is a flood receiving areas map. At this point a good understanding of watershed behaviour has been garnered, allowing for a better understanding of why certain areas in the watershed are more prone to flooding than others. The high hydrologic connectivity between the small, steep watersheds and short river reaches make the Garden Route watersheds highly responsive. During rainfall events, runoff generated on the mountain slopes, is funnelled through narrow incised rivers into flood receiving areas in the lower lying areas where there are waterbodies, and floodplains and settlements located near rivers. This information provides a starting point for identifying and prioritising areas where flood mitigation measures need to be put in place..

3.5.4 Strengths and limitations of the approach

The data required to set up a hydrological model is one of the main constraints when choosing a model to apply to a specific area. One of the main strengths of the SCIMAP model is that it can be run with the use of readily available data sources such as national land cover maps, digital elevation models and soils data. In addition, the framework is not computationally demanding, and can be run without extensive modelling expertise. The outputs of the model are spatially explicit maps, which make the presentation of results and their interpretation easier. The model's strength is that that it incorporates a representation of hydrological connectivity, with additional model sub-components of stream power and runoff generation that allow consideration of a range of environmental processes and how they link and interact with land management. Final results can also be returned to GIS and overlain with existing maps and watershed information for further analysis. Compared to other more complex hydrological models, the SCIMAP model does have limitations. Although it can identify flood-exposed areas, it cannot simulate hydrological parameters of water velocity, depth and discharge.

3.5.5 Conclusion

The potential use of the Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) to capture, assess and identify flood receiving areas was tested. The identification of flood receiving areas is a fundamental component of a flood management strategy and allows for the anticipation of possible impacts and the prioritisation of resources. The case study of the Garden Route watersheds illustrates how this approach can be used at a watershed scale to not only to identify flood receiving areas, but to provide a better conceptual understanding of the physical processes in the watershed and its underlying drivers. The comparison of the flood receiving area map with historical flood events, suggests that the locations of flood receiving area identified by the SCIMAP model are areas prone to flooding. The approach shows great potential as a decision support tool for improved flood management and is intended to be used in the preliminary stages of a study to prioritise areas in the landscape where future resources, time and expertise should be focused.

3.6 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field. Ecosystem Management Series no. 9* .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem

services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward. 2015a. Linking biodiversity, ecosystem services, and human well-being: three

challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and Resources* 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral Research* 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O'Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth Surface Processes and Landforms* 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland’s valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil

roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

Garen, D. C., and D. S. Moore. 2005. “Curve number hydrology in water quality modeling: Uses, abuses, and future directions,” - Reply to discussion. *Journal of the American Water Resources Association* 41(6):1493–1494.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in

integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D.

Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors).

Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale

environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature's benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for

a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services.

Progress in Physical Geography 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the

case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity* 12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*

8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O’Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O’Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of*

Disaster Risk Reduction 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*.

Garden. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance.

Ecological Modelling 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth 's climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-

Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E., & Smithers, J. C. (2007). One day design rainfall. In R. E. Schultze (Ed.), *South AFrican Atlas of Climatology and Agrohydrology*. Pretoria, South Africa: Water Research Commission, WRC Report 1489/1/06, Section 6.8.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the “regulating” services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A multi-stakeholder approach to targeted intervention in selected municipalities*. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International* ….

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB*.

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning* *and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems : A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 4

Piloting a social-ecological index for measuring flood resilience: A composite index approach

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4.1 Abstract

Global increases in the magnitude and frequency of flood events have raised concerns that traditional flood management approaches may not be sufficient to deal with future uncertainties. There is a need to move towards approaches that manage the resilience of the system to floods by understanding and managing drivers of vulnerability and adaptive capacity. Here we pilot an approach to measure the resilience of a system to a flood. A method is presented in which indicators are used to measure and map the spatial distribution of the levels of flood resilience across a landscape. Using three flood affected municipalities in South-Africa, 24 resilience indicators related to floods and its relevant social, ecological, infrastructural and economic aspects are selected, and integrated into a composite index using a principal components analysis (PCA). A fifth component of institutional resilience is used to explore levels of disaster planning, mitigation and public awareness capacities and where these can be increased. The PCA transformed the 24 variables into four main components, the first of which was strongly correlated with underlying social variables, while the second and third correlated well with economic and ecological variables respectively. Distinct spatial variation of flood resilience was found across the study area, with highest flood resilience in main cities, and lowest in wards located on the periphery of cities often the location of peri-urban informal settlements. The disaggregation of underlying indicators showed wards with lowest flood resilience also had the lowest social, economic and ecological resilience. The flood resilience index was sensitive to the exclusion of all three components highlighting the importance of capturing the multidimensionality of flood resilience. The approach allows for a simple, yet robust index able to include an array of datasets generally available in flood prone areas with potential to disaggregate and trace variables for management and decision making.

Keywords: Extreme events; Social-ecological systems; Disaster management; Indicator, Ecosystem service; Climate change

4.2 Introduction

Increases in extreme weather events combined with expanding urban populations are leading to progressively more vulnerable people and assets. High population densities, lack of urban infrastructure, ubiquitous informal settlements and urban sprawl to marginal areas mean that cities in developing countries are particularly exposed to climate change-induced disasters like floods, sea storms and wildfires (Pelling and Özerdem 2002, Thakur et al. 2011). Studies on the impacts of severe flood events in the last decade report on unpredictable, usually rapid onset events, that lead to substantial financial losses, destruction of infrastructure, displacement, and death (Merz et al. 2007, Armah et al. 2010).

The magnitude and frequency of these events suggest that traditional approaches of flood management are no longer adequate. Resilience approaches aimed at understanding and managing the capacity of a social-ecological system (SES) to adapt to, cope with, and shape uncertainty and surprise offer a possible avenue to deal with these challenges (Folke et al. 2002, Adger et al. 2005). Social-ecological systems (SES) are interdependent systems of people and nature. The way in which SES copes and adapts to changes therefore needs to be analysed in a way that accounts for social-ecological interactions (Chapin et al. 2010). In a resilient SES, dealing with disturbance such as floods present an opportunity for innovation and development in a changing environment (Folke 2006, Turner II 2010). The ability of a SES to adapt to and benefit from change is dependent on characteristics of vulnerability and adaptive capacity (Walker et al. 2004). "Vulnerability is the degree of harm owing to exposure and sensitivity to a specific hazard and the absence of the capacity to adapt" (Adger 2006). Whereas the capacity to adapt refers to the ability of actors in a system to influence resilience through collective action and learning (Walker et al. 2004).

In order to manage and foster the resilience of systems to floods, it is important to be able to measure where, and how much resilience resides in a system (Carpenter et al. 2001, Walker et al. 2002). Complex interactions between social and ecological systems, non-linear feedbacks, spatial and temporal variation, and the practical difficulties of measuring resilience, make operationalising resilience challenging (Marshall and Marshall 2007, Davidson et al. 2013). Some of the tools and models that have been used to measure resilience include the use of ecological models (Cumming et al. 2005, van Nes and Scheffer 2007), indicators (Chillo et al. 2011, Dai et al. 2012), metrics (Allen et al. 2005), and resilience surrogates (Bennett et al. 2005). Due to a lack of sufficient data and capacity, uncertain model results and insufficient guidelines for use by scientists and managers, tools and models have remained substantially under-utilised in SES management (Nyström et al. 2008, Malone and Brenkert 2008). There is therefore a need for a readily calculated and transparent method to measure resilience of a SES to stresses and events such as floods (Chapin et al. 2010).

Composite indices offer a potential avenue for dealing with the multivariate and complex nature of SES. A composite index is a mathematical aggregation of a set of indicators used to summarise the characteristics of a system (Saisana and Tarantola 2002, Salvati and Carlucci 2014). Indices are increasingly used to facilitate communication among scientists, policymakers, and the public (Reisi et al. 2014). Their application include the measurement of trends in poverty, human development, vulnerability and quality of life and biodiversity (Scholes and Biggs 2005, Hahn et al. 2009, Krishnan 2010, Flanagan et al. 2011). Part of the appeal of composite indices lie in their ability to provide the big picture while summarising complex or multi-dimensional issues (Saisana and Tarantola 2002). As decision-making tools they are not without limitations, which include challenges of disaggregation and traceability for management (Scholes and Biggs 2005, Hinkel 2011).

The use of composite indices to measure disaster resilience has largely been developed in social science and environmental risk and hazard communities (Mayunga 2007, Cutter et al. 2010, Orencio and Fujii 2013). In these indices the emphasis is on community resilience which implies that groups or communities are resilient due to social and organisational factors which enable them to respond and adapt to disasters (Cutter et al. 2008, Magis 2010, Frazier et al. 2013). A potential shortcoming of these indices has been the absence of a biophysical component. This is an important gap as ecosystems have been shown to play a large role in determining resilience to extreme events associated with climate change impacts (Munang et al. 2013, Nel et al. 2014). In the disaster resilience index of Cutter et al.(2014) a first attempt at the inclusion of an ecological resilience component is made. The index however measures general resilience to all natural hazards, rather than specific resilience to a particular hazard. In order to account for different ecosystem features and processes associated with particular hazards a more specific resilience focused on a particular natural hazard would allow for the selection of variables relevant to the hazard while capturing more accurately the role, location and condition of ecosystem services.

To contribute to approaches and studies operationalising resilience, especially those that elaborate the social-ecological dimensions of resilience, we develop, test, and analyse the use of a flood resilience index. This study makes use of the social and ecological characteristics of three flood-prone municipalities in South Africa. The method is developed within the context of existing tools and methodological frameworks used in urban and disaster planning, in order to link to future policy and planning in the area.

4.3 Methods

4.3.1 Study site description

The study area is located in the coastal region of the Southern Cape of South Africa. The three municipalities in the study area; George, Knysna, and Bitou, consist of an interconnected system of urban centres, towns, villages, and hamlets that form part of the Eden District (Fig 4.1). Municipalities are politically created boundaries, sub-divided into wards which can include part of a settlement, and one or more suburbs or residential areas depending on its size. The Eden district has been evaluated as one of the five most disaster-prone areas in South Africa as it is very mountainous, prone to flash flooding, and coastal sea storms (SALGA) (2013). It has also been the subject of long-term ecological and social data collection and analysis (Reyers et al. 2009, Payet et al. 2013, Sitas et al. 2013, Nel et al. 2014). The three municipalities chosen for the study have been the hardest hit by flood events in South-Africa within the last decade (Macgregor 2005, Faling et al. 2012).

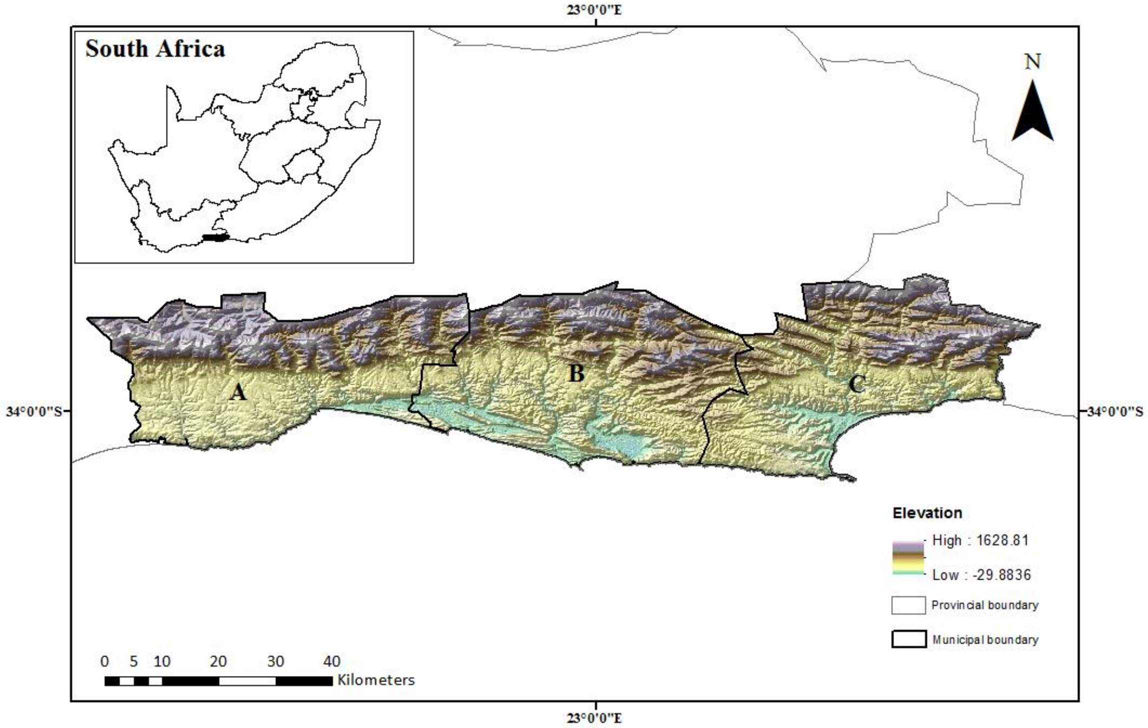

Figure 4.1: Map of the study area showing its location in South Africa, and three municipalities of A George, B Knysna and C Bitou.

The Eden District falls within three internationally recognised biodiversity hotspots (Vromans et al. 2010). The area hosts an extensive system of indigenous forests and is home to a number of unique lakes and estuaries that are of both scientific and economic importance (Turpie et al. 2002, Maree 2010). The local economy is largely centred on tourism, agriculture, manufacturing, forestry, and trade (Ferreira 2007, Pauw 2009). Rapid population growth attributed to the net in-migration of young, low-skilled job seekers and older, high-income retirees have placed increased pressure on existing infrastructure, and demand for housing (Eden District Municipality 2009). This urbanisation pressure is set against a backdrop of very limited developable land, a sensitive environment, and a lack of new jobs being created in the local economy (Allanson 2000, Marker 2003).

4.3.2 Construction of the index

Various methods exist to construct composite indices, with the choice of method dependent upon the type of problem, the nature of the data and the objective of the analysis (Nardo et al. 2005). The use of composite indices to measure resilience is fairly new, and the accurate characterisation of resilience still remains a challenge (Prior and Hagmann 2013). Many disaster resilience indices use an equal weighting for reasons of simplicity and transparency (Cutter et al. 2010, Ainuddin and Routray 2012). We rather assign an explicit and transparent weighting system to account for the range of variance in such a social-ecological dataset and conduct sensitivity analyses to make clear its impact. The statistical method of principal component analysis (PCA) is used to generate weights for the variables. PCA is a statistical model which relies on the variation and covariation of the data matrix to construct weights in the component index (Saisana and Tarantola 2002). The weighting method is objective, computationally easy and is compatible with the type of data obtained from surveys and databases (Vyas and Kumaranayake 2006).

4.3.3 Variable selection

As flood resilience is a multifaceted property, we used the principles of resilience as outlined by Biggs et al.(2012) to guide our selection of variables with which to measure resilience. These principles include maintaining diversity and redundancy, managing connectivity, managing slow variables and feedbacks, fostering of complex adaptive systems thinking, encouraging learning and broadening participation. In a review of public and grey literature relevant to flood resilience the factors shown to be linked to social, economic, infrastructural and ecological flood resilience (Cutter et al. 2008, Gunderson 2010) were identified and then refined using the Biggs et al. (2012) criteria, as well as data availability in the region. Of the selected 30 variables, 6 showed high levels of correlation (Pearsons R> 0.7) which were removed. A final 24 variables were selected for use in the index (Table 4.1).

4.3.4 Data sources

Data for variables were collected at the ward level and obtained from the 2011 Census of South Africa (Statistics South Africa 2011), as well as government publications, municipal planning documents and an online biodiversity database (BGIS 2014). All data used were taken from public databases to ensure that the final result could be validated, reproduced, replicated and improved with new data by stakeholders.

Table 4.1: Description of variables used to assess flood resilience in the Eden District.

Variable	**Description**
Access/evacuation potential ℧	Arterial roads/ km^2
Age dependency ratio	Pop aged under 15 or 65+ to total pop aged 15-64.
Civic involvement	Number of civic organizations per ward/10 000 pop.
Communication capacity	% Population owning a cell phone.
Children under 5 years of age	Population aged 0-4
Ecological Buffer	% Natural vegetation.
Education	% Population with a high school diploma.
Elderly	Population aged 65 and older.
Employment	% population employed.
Employment equity	% female labour.
Employment sector diversity	TRESS index
Housing capital	Percent home-ownership.
Housing type	Percent formal housing
Income disparity	Percentage population earning > $400
Land use diversity	Proportion of land use categories per ward, multiplied by the natural logarithm. The resulting product is summed across wards, and multiplied by -1.
Place attachment	% Population living in area for 10+ years.
Political Engagement	Voter participation in local elections.
Recovery ℧	% Public schools per ward.
Soil retention	Percentage deep permeable soil per ward.
Special needs	% Population without a sensory or physical disability
Transportation Access	% Population with a vehicle.
Water infrastructure Water infrastructure	% Piped water. % Flush toilets.
Wetland diversity	Proportion of flood attenuating wetlands per ward, multiplied by the natural logarithm. The resulting product is summed across wards, and multiplied by -1.

℧ Natural log transformation: New variable =Ln (1+Old variable).

4.3.5 *Normalisation and appropriateness procedures*

To standardize variables a min-max normalisation technique was performed on all variables (Priddy and Keller 2005). The statistical software IBM SPSS Statistics version 21(IBM Corp 2012) was used to carry out all statistical procedures. The selected variables were inspected for normality using the Kolmogorow Smirnov statistic, and descriptive statistics of skewness and kurtosis to identify data distribution. To correct for skewness in the data the variables of recovery, and evacuation potential were statistically transformed using a natural logarithm (Table 1). The suitability of using a factor analysis was tested using Bartlett's test and Kaiser-Meyer Olkin (KMO) measure. Both tests provided sufficient statistical significance and factors were found suitable for performing a PCA.

4.3.6 *Principal Component Analysis*

PCA identifies patterns and reveal underlying factors that best describe variation in the data (Kaźmierczak and Cavan 2011). The objective of the analysis is to take Q variables $x_1, x_2 \ldots\ldots x_q$ and find linear combinations of these to produce principal components $Z_1, Z_2 \ldots Zq$ (Nardo et al. 2005). Each component reveals the set of variables with which it has the strongest correlation, and this is used to weight the variables of the composite index.

The first step in PCA is to check the correlation between variables; this was done through performing a correlation matrix on the 24 variables chosen. The second step is to identify a certain number of latent components that represent the data. To determine the number of components to be extracted a scree test is used (Cattell 1983). After an examination of the scree plot, four components were extracted for analysis. Factor loadings were then calculated for each of the variables on the components. To minimise the number of individual variables that have a high loading on a specific component a varimax rotation was performed on the data.

4.3.7 *Calculating the flood resilience index (FRI)*

Once the principal components were extracted an intermediate sustainability indicator (ISIji) corresponding to each of the principal components j was needed. This was done through a weighted aggregation of indicators(Gómez-Limón and Riesgo 2008):

$$IRI_{ji} = \sum_{k=1}^{k=n} w_{kj} I_{ki} \qquad 1$$

Where IRI_{ji} is the intermediate resilience indicator for the component *j* and the ward *i*, and w_{kj} is the weight of indicator *k* in the component *j* and *Iki* is the normalised indicator k achieved by ward *i*

The weights wkj are obtained from the varimax rotation (Table 2) following this expression:

$$w_{kj} = \frac{(factor\ loading_{kj})2}{eigenvalue_j} \qquad 2$$

The FRI is calculated as a weighted aggregation of the intermediate resilience indicators:

$$FRI_i = \sum_{j=1}^{j=3} \alpha_j IRI_{ji} \qquad 3$$

Where FRI*i* is the value of the composite indicator for the ward *i* and α is the weight applied to the intermediate sustainability indicator j. These weights are calculated as follows

$$\partial_j = \frac{eigenvalue_j}{\sum_{j=1}^{j=3} eigenvalue_j} \qquad 4$$

The result of the index scores can be negative or positive and was standardised using min-max normalisation (Priddy and Keller 2005). To test whether components were well balanced and produced a robust composite index, robustness analyses were undertaken to determine the influence of weights and variable choice on the index output. This included testing of weighting effects by computing an equal weighted index and comparing it to the empirically weighted index. The resilience index scores for both weighting schemes were then ranked and compared. The impact of choice of variables used was tested by systematically including and excluding variables measuring social, economic and ecological resilience.

4.3.8 Data visualisation and classification

The flood resilience index (FRI) scores, were made spatially explicit using Geographic Information Systems (GIS) version 10.0 (ESRI 2010). To facilitate further exploration of geographic trends in the data, the intermediate resilience indicator (IRI) scores for the three components of social, economic and ecological components were also made spatially explicit. Data were displayed based on standard deviations from the mean, to highlight wards that rank high or low in terms of their flood resilience.

4.3.9 Institutional resilience

Due to the nature of institutional resilience, many of the indicators do not lend themselves to qualitative measurement. A scoring system was therefore developed drawing on key characteristics of organisational capacity known to favour institutional resilience (Næss et al. 2005, Brody et al. 2009, Miao et al. 2013). Following the safety chain approach (ten Brinke et al. 2008) indicators were grouped into four phases of flood management: pro-action, preparation, response, and recovery. Municipalities were allocated a score of one if compliant, a score of 0.5 if policies or measures are in place, but not adequately implemented and a score of zero for no compliance. Compliance was assessed based on the review of each municipality’s strategic planning documents, which includes integrated development plans (IDP), spatial development frameworks, as well as official websites and press releases. Due to the more subjective, qualitative approach used to measure institutional resilience, it was kept separate from the composite index development and only assessed in comparison to the final index.

4.4 Results

4.4.1 Component scores

The PCA found that the first four components together explained 68% of the variation in the data, with the first, second, third, and fourth components, accounting for 23, 21.55, 13.9 and 9% of the variance respectively (Table 4.2). Variables of education, communication capacity, employment, transportation access and elderly population scored highly on component one, with high negative loadings for variables of place attachment and children under the age of five (Table 4.2). Based on the predominance of social variables on component one it was classified as a social resilience component. Variables that loaded highly on component two include water infrastructure, income disparity and employment equity with a high negative loading for the age dependency ratio variable (Table 4.2). Component two was classified as the economic resilience component. Variables of ecological buffers, employment sector diversity and land use diversity loaded highly on component three, with a high negative loading for soil retention (Table 4.2). Based on these variables the component was classified as ecological resilience component. Component four had only two high loading variables explaining the relationship between wetland diversity(negative) and access/evacuation potential (positive) (Table 4.2).

Table 4.2: Results of Principal Component Analysis using a varimax rotation factor matrix

Variables	Component			
	1	2	3	4
Education	0.827			
Communication capacity	0.802			
Place attachment	-0.797			
Employment	0.753			
Transportation access	0.727			
Elderly	0.711			
Children under 5 years of age	-0.706			
Civic involvement	0.647			
Political engagement	0.536			
Special needs	-0.369			
Schools	0.319			
Water infrastructure		0.869		
Income disparity		0.823		
Employment equity		0.815		
Housing type		0.759		
Housing capital		0.732		
Age dependency ratio		-0.595		
Ecological buffers			0.840	
Employment sector diversity			0.812	
Soil retention			-0.766	
Land use diversity			0.646	
Sanitation infrastructure		0.476	-0.520	
Wetland diversity				-0.855
Access/evacuation potential				0.675

4.4.2 *Flood resilience Index*

The distribution of the calculated flood resilience index (Fig. 4.2), demonstrate the large variability in flood resilience across the study region. The highest flood resilience scores were found in the main towns and surrounding suburbs of the three municipal areas. Moderate flood resilience was observed in the outer wards which form the boundary of the municipalities. Lowest flood resilience was found in the urban wards situated on the periphery of main cities.

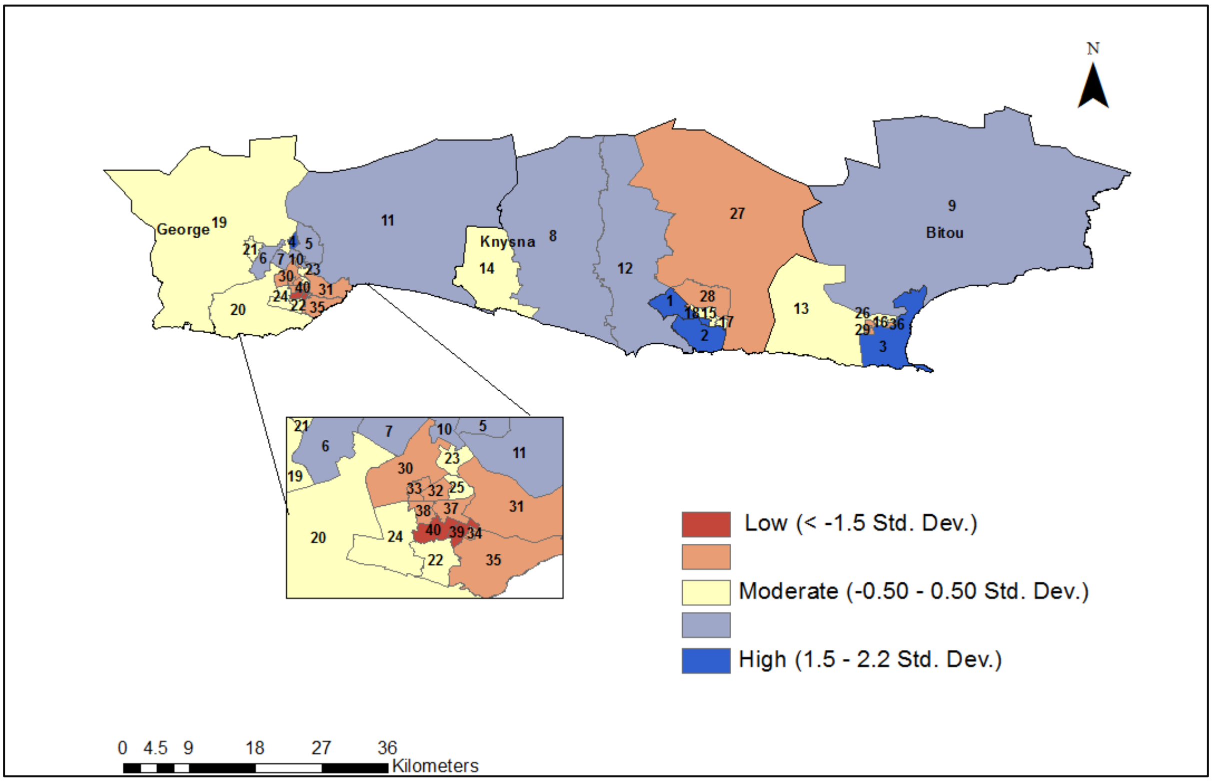

Figure 4.2: Spatial distribution of flood resilience Index (FRI) values and their related ward ranking for the Eden District. Wards are ranked from most (1) to least (40) resilient. Classes are measured in +/- intervals of 0.5 std dev from the mean. Those greater than the mean are accorded a high ranking, while those less than the mean are lower ranked.

The underlying factors influencing flood resilience become clearer when the index is disaggregated into its component parts (Fig. 4.3). The distribution of social resilience (Fig. 4.3(a)) shows the highest scores are within wards containing the three main cities of the respective municipalities. High scores were also found in the outer wards bordering the municipalities of George and Knysna. Moderate scores were found in wards made up of towns and villages adjoining the urban wards. Low scores were found in peri-urban wards on the periphery of main cities. In terms of economic resilience (Fig. 4.3(b)) highest scores were measured within and around city centres, with progressively lower resilience with distance from urban centres, with the exception of Bitou municipality, which had predominantly moderate scores. The distribution of ecological resilience (Fig. 4.3 (c)) shows relatively high ecological resilience in the majority of wards. Highest scores were found in the two connected wards in the eastern side of the study area. The western side of George municipality displayed the lowest scores of the region with moderate scores for the wards forming the border of the municipality and low to very low scores in peri-urban wards.

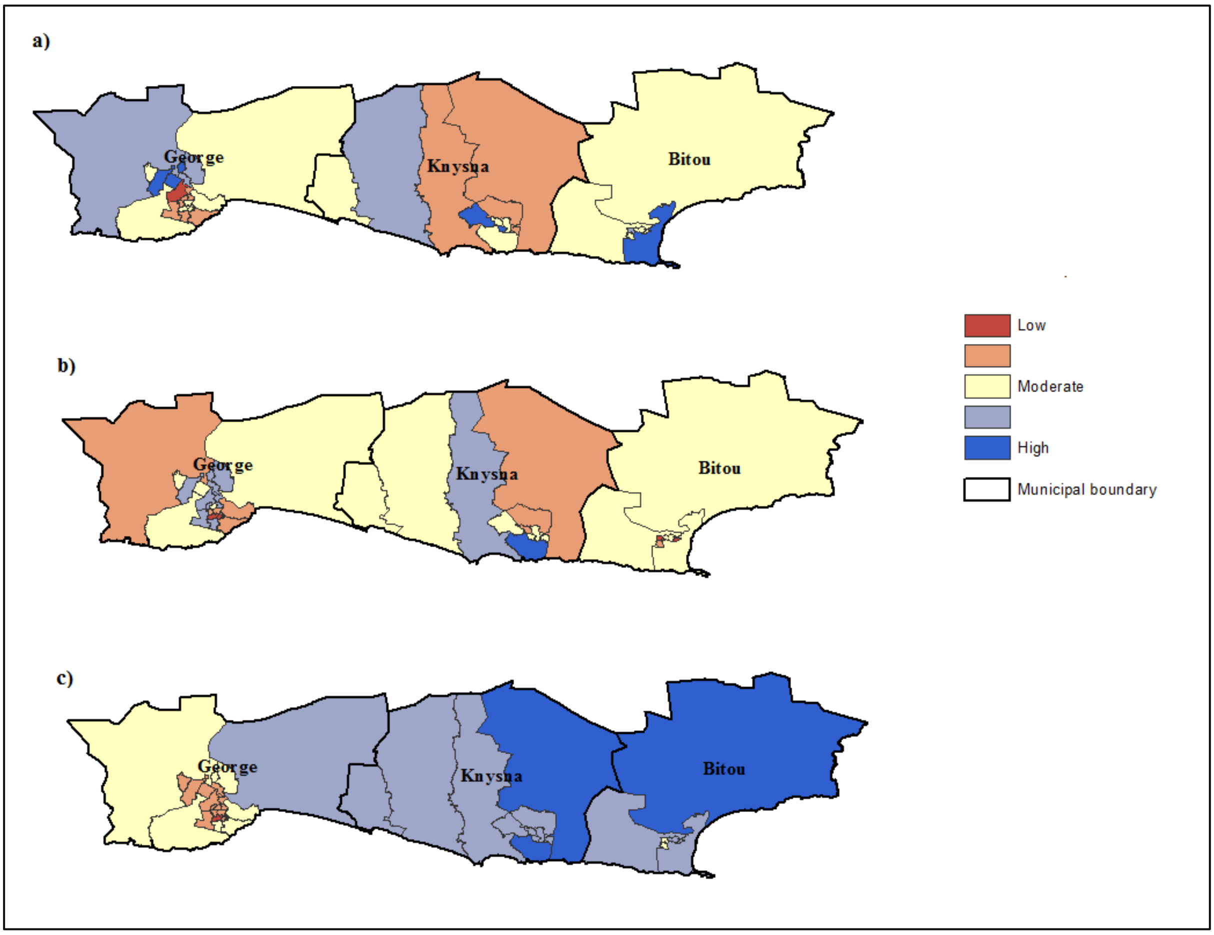

Figure 4.3: Spatial distribution of disaggregated components of the flood resilience index; showing (a) social resilience, (b) economic resilience and (c) ecological resilience values. Classes are measured in +/- intervals of 0.5 std dev from the mean. Those greater than the mean are accorded a high ranking, while those less than the mean are lower ranked.

Scores for institutional resilience are shown in Table 4.3. The highest scores were measured within the pro-action and prevention phase for all three municipalities. In the preparation phase all three municipalities had fairly low scores with the highest scores calculated for George municipality, and lowest scores calculated in Knysna municipality. Recovery phase was the lowest scoring phase, and all three municipalities displayed scored zero indicating non-compliance.

Table 4.3: Institutional resilience variables and their associated scores for components of flood management cycle. A score of 1 represent compliance, a score of 0.5 represents inadequate implementation, and a score of zero represents non-compliance.

Measure	**George**	**Knysna**	**Bitou**
Pro-action			
Spatial Development Framework	1	1	1
Zoning Ordinances	1	1	1
Building standards	0.5	0.5	0.5
Flood setback lines	0.5	0.5	0.5
Transfer of development rights	1	1	1
Risk reduction programs	0	0.5	0.5
Infrastructure maintenance	0	0	0
Preparation			
Training for disaster risk	0.5	0.5	0.5
Guidelines for early warning	0	0	0
GIS data for disaster management	0	0	0
Drills for disaster response	0	0	0
Flood Education	0.5	0.5	0.5
Vulnerability assessment	0.5	0.5	0.5
Active stakeholder engagement	1	0	0
Dedicated disaster management staff	1	0	0
Collaboration with NGO's and civil society	0	0	0
Budget	0.5	0.5	0.5
Storm water management plan	0.5	0.5	0.5
Response			
Disaster Recovery plans	0	0	0
Communication amongst emergency responders	1	1	1
Flood warning and forecasting	0.5	0.5	0.5
Recovery			
Debriefing and post disaster recovery	0	0	0
Interoperable communication	0	0	0
Disaster Management advisory forum	0	0	0

4.4.3 Weighting and its impacts on FRI

Rank values for the two weighting schemes are summarised and compared in Fig. 4.4. Results show good correlation in the outputs obtained for the two weighting options, with minimum and maximum values remaining within the same range for all municipalities. Boxplots show a marked difference in the distribution of rank values, with the empirical weighted index showing a larger, upward distribution in rank values.

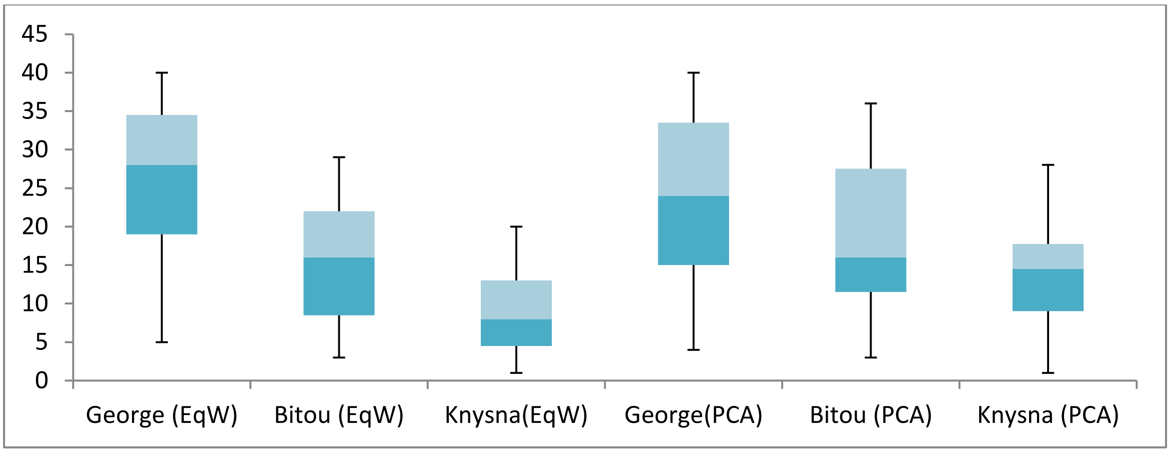

Figure 4.4: Summary of the ranking of the flood resilience index (FRI) at municipal level, computed with equal weight (EqW) and empirical weight (EmW). The top and bottom of the box represent the 25th and 75th percentiles (quartiles), and the horizontal lines extending out of the boxes represent the 5th and 95th percentiles. The middle horizontal line within each box indicates the median of the data.

The sensitivity of the FRI to the inclusion or exclusion of variables are assessed and summarised with the use of box and whisker plots in Figure 4.5. The inclusion and exclusion of variables had varying effects on the FRI scores of all municipalities. In the iteration where variables measuring ecological components were excluded a downward shift in minimum scores was observed for all three municipalities, in Bitou resilience scores clustered within a narrow range around the median, with a long tail indicating a large dispersion in the relative outliers, whereas resilience scores for George and Knysna showed a very similar distribution. The exclusion of variables measuring economic components showed no change in minimum and maximum values, but a greater dispersion in resilience scores. The exclusion of the variables measuring social components resulted in a downward shift in minimum values for all three municipalities, with a greater distribution of resilience scores in Knysna municipality.

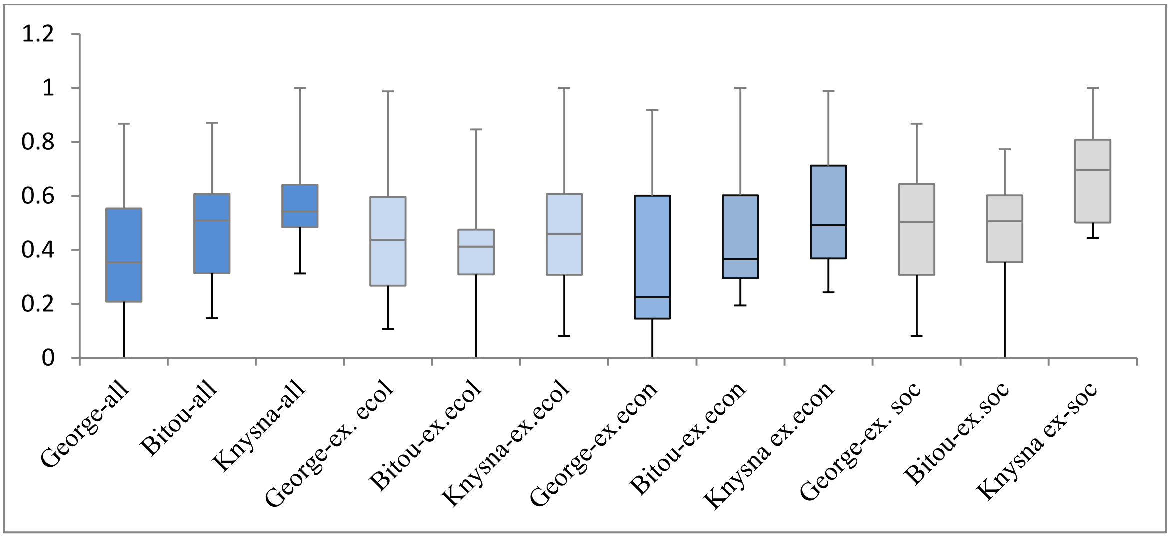

Figure 4.5: Summary of estimated flood resilience index (FRI) values using all components (all), excluding ecological components (ex.ecol), excluding economic components (ex.econ) and excluding social components (ex.soc). The top and bottom of the box represent the 25th and 75th percentiles (quartiles), and the horizontal lines extending out of the boxes represent the 5th and 95th percentiles. The middle horizontal line within each box indicates the median of the data.

4.5 Discussion

In developing and piloting a multi-dimensional approach to measuring resilience in three flood prone municipalities, this study demonstrates the possibility of the spatial depiction and communication of flood resilience values. The findings highlight the variation across the region from highly resilient inner city wards, to low levels of flood resilience within wards located on the periphery of main cities. The approach further allows for the disaggregation and traceability of the underlying components of social, ecological, and economic and infrastructure resilience, in order to explore and manage the major determinants or detractors of flood resilience. The independent institutional resilience component further helps to explore which capacities related to disaster planning, mitigation and public awareness are lacking and need to be managed to improve flood resilience in the area.

4.5.1 Flood resilience in Eden

High flood resilience scores in urban coastal wards, is expected as it is located in areas with a strong natural resource base. These characteristics are major drawing card for the wealthy residents who live there, and contribute to the high social and economic resilience of these wards (Tempelhoff et al. 2009). Rural wards on the borders of municipalities are key agricultural and social support centres, but lack sufficient infrastructure, reflected in the moderate flood resilience scores (Eden District Municipality 2009). Rural wards of the study area did however score higher than urban wards located on the outskirts of city centres.

These urban wards contain informal settlements, which are characterised by poorly built and inadequately maintained housing, sited on inappropriate landscapes that are poorly drained (Benjamin 2008). Moreover residents of these wards often have insufficient financial and other resources to prepare for floods, and therefore typically suffer greater housing damage, have higher mortality rates, and recover more slowly after a flood event (Morrow 1999).

Social resilience is the most statistically significant indicator of flood resilience in Eden with highest social resilience scores in the main cities which are the centres of housing, health and education facilities and have the highest concentration of work opportunities (Godschalk 2002, Eden District Municipality 2009). Rural wards also display high social resilience, which can be attributed to the strong network of social ties within these communities (Murphy 2007, Norris et al. 2008). Strong social networks or social capital as it is also known can increase both response and recovery before during and after flood events (Morrow 2008, Carpenter et al. 2012). Individuals living in the rural wards of the study area are likely to have lived in the area for an extensive period of time, during which they have greater community interaction and stronger personal bonds (Krishna and Shrader 1999). Fast growing urban wards however are more likely to contain isolated households with limited networks to draw upon during flood events (Morrow 1999) which is reflected in the low social resilience scores in the peri-urban wards.

Economic and infrastructure resilience which is tightly linked in the Eden District is the second most statistically significant indicator of flood resilience in the Eden District. This is highlighted in the more affluent wards, where residents are in a better position to pay for, and demand better infrastructure. The lowest scores were measured in the urban wards on the outskirts of the city. The urban wards furthest away from the central business district suffer from inadequate social facilities and poor integration with the rest of the wards in the municipality, and are generally also the areas of greatest poverty (Benjamin 2008).

The study area has a high natural resource base, which is reflected in the high resilience scores across municipalities. The lowest ecological resilience was measured in the urban wards of George municipality which are also the most populous wards of the study area(Statistics South Africa 2012). The concentration of people around urban centres can have impacts on local biodiversity through the over-use of provisioning services such as freshwater, crops and timber (Adger et al. 2005, Pauchard et al. 2006). Urban areas, in which land use diversity is maintained, will have more options for responding to change and disturbance (Chapin et al. 2009; Biggs et al. 2012). Investment in ecosystem service-based economic activities such as eco-tourism and fishing can enhance economic resilience while maintaining ecosystem services (Raudsepp-Hearne et al. 2010).

There is room for improvement within all three municipalities for all phases of flood management. In the pro-action phase authorities should endeavour to separate the source of risk from the population in order to avoid a disaster (ten Brinke et al. 2008). A review of pertinent literature shows that although zoning and building controls are in place for all three municipalities, there is a gap between flood risk management policies and its implementation. The main hurdles faced by the local municipalities are poor land use decisions in the past, rapid urbanization, and lack of formal housing (Benjamin 2008, Humby 2012). In the preparation phase of the disaster management cycle arrangements, contingency plans and crisis management training takes place (ten Brinke et al. 2008). The absence of dedicated disaster management personnel in any of the municipalities is disconcerting as a strong organizational capacity forms the basis of good institutional resilience (Brody et al. 2009). This is especially important in the wake of climate change-induced flood hazards which may place new and unexpected demands on municipal authorities (Brown and Damery 2002). By employing a dedicated disaster management team, more technical expertise and personnel can be devoted to the implementation of good flood mitigation techniques (Brody et al. 2009, Miao et al. 2013). This could also have positive knock-on effects for the other phases of the flood management cycle. The recovery phase is one of the most important phases in the flood management cycle as it provides feedback to the other phases, and can aid in making communities less vulnerable to similar events in future (ten Brinke et al. 2008). The recovery phase was however the lowest scoring for all three municipalities. When compared to that of the response phase, very little attention in general is given to coordination in disaster recovery. Post disaster efforts can be increased through collaboration with other government departments as well as closer collaboration with non-governmental organizations (NGOs) and civil society (Raju and Van Niekerk 2013).

4.5.2 Robustness analysis

As with all composite indicators, choices of variables, weighting and calculation influence the final outcome (Gómez-Limón and Riesgo 2008, Salvati and Carlucci 2014)). The use of weights and the selection of weighting method depend on the local factors and situations where the method is applied (Mayunga 2007, Reisi et al. 2014). For this case study, which like many developing countries displays high social and economic disparities, the method relying on the variation and covariation of the data matrix to construct weights provided a useful discriminant of flood resilience. The robustness analysis on variable choice was useful in identifying the variables which exert a significant influence on the output of the index. The analysis highlighted the importance of the use of a multi-dimensional approach in which all components of resilience are included. The results also showed how the resilience of municipalities was affected by variable inclusion, which helped to increase transparency of the index.

4.5.3 Conclusion

In assessing the resilience of communities to floods, a composite index and spatial analysis approach proved helpful in summarising and presenting a complex array of variables linked to resilience in a repeatable and replicable manner. Outputs of the composite index are meaningful, traceable, disaggregatable and relatively intuitive to interpret. The inclusion of the institutional resilience component is important for improving government policy and floods management. Spatial analysis gives further insights into the geographic distribution of flood resilience across the study area and highlights the disparity between inner city wards and those on the urban fringe. The applied value of the flood resilience index lies in its potential to inform decision making grounded in credible, salient and transparent information. While developed in the Eden district, the method is flexible enough to allow the proposed index to be applied in other geographic locations. The use of PCA as a method to construct this index allows it to be adapted to specific contexts as the defined weights are based on underlying variables and variation in selected variables. Although Eden is relatively data rich, especially with regards social data, the increasing availability of an array of global social, economic and ecological datasets (Tallis et al. 2012) make it possible to apply, test and refine this flood resilience index elsewhere. The strength of the index is that its components are disaggregatable, allowing for the identification of the main drivers of flood resilience within a ward. It can thus be used to recognize the components which lead to improved resilience and to set targets to improve the resilience of low scoring areas.

4.6 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field. Ecosystem Management Series no. 9* .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem

services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward. 2015a. Linking biodiversity, ecosystem services, and human well-being: three

challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and Resources* 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral Research* 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O’Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth Surface Processes and Landforms* 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland’s valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil

roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

Garen, D. C., and D. S. Moore. 2005. "Curve number hydrology in water quality modeling: Uses, abuses, and future directions," - Reply to discussion. *Journal of the American Water Resources Association* 41(6):1493–1494.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in

integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D.

Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors).

Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale

environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature’s benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for

a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services.

Progress in Physical Geography 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the

case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity* 12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*

8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O’Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O’Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of*

Disaster Risk Reduction 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*.

Garden. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance.

Ecological Modelling 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth 's climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-

Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E. 2008. *South African atlas of climatology and agrohydrology*. Pretoria.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the “regulating” services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A*

multi-stakeholder approach to targeted intervention in selected municipalities. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International …*.

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB.*

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in

the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems : A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 5

Assessing and mapping supply and demand of flood regulation: broadening understanding through a systems perspective

This chapter is intended for submission to the Journal *Ecosystems* as:

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5.1 Abstract

Although major strides have been made in the quantification of ecosystem services to date, there has been a lack of approaches and information to quantify and map supply and demand of flood regulating services in a linked and useful way. This paper introduces and illustrates an approach to characterise and spatially connect the flood regulating ecosystem service flows from supply to demand. The approach used includes a resilience perspective in which a people centred priority is adopted which fits the inequality and development challenges experienced by many developing countries. Supply and demand of the flood regulating service was spatially defined using widely available and regularly updated geophysical GIS and national census data to ensure that changes in the system can be captured over time. The spatial location of the supply of the flood regulatory service was determined using a risk based model with outputs classified into service providing, connecting and benefitting areas. Demand for flood regulation was estimated by relating the flood hazard to exposure and social and economic resilience of downstream areas. To illustrate the variation in supply and how humans shape the demand for regulating services, the approach was applied in two urban watersheds in South Africa. In the George watershed the service providing area constitutes 37% of the watershed, with runoff largely generated in the upper mountainous part of the watershed and along the coast. In the Knysna watershed service providing areas make up 20% of the watershed and comprise urban areas, plantations and thicket or dense bush. A clear spatial distinction was shown in the demand for flood regulation in the watershed with generally low demands in the urban wards, and high demand for flood regulation in the peri-urban wards. The approach is flexible and could include other aspects of exposure such as land or urban assets. It also allows for disaggregation to explore underlying features, as well as the regular updating of new data to account for the dynamic nature of the social and ecological components of these areas.

Keywords: Social-ecological systems; Resilience; Ecosystem services; Vulnerability; Regulating services.

5.2 Introduction

Since the publication of the Millennium Ecosystem Assessment (MA) there has been a growing focus on the prevention of environmental decline and degradation, with considerable research effort placed on understanding the intricate linkages between the natural environment, economic development and human well-being (MA 2003, Howe et al. 2013, Bennett et al. 2015a). Central in this undertaking has been the use of an ecosystem service approach aimed at sustainably managing ecosystems to deliver services that will benefit society despite ongoing disturbance and transformations (TEEB 2010, de Groot et al. 2010, Biggs et al. 2012). Ecosystem services, which have been grouped into four broad categories of provisioning, regulating, cultural and supporting services, have been studied extensively over the past decade with major strides made in many areas of ecosystem service research and practice (Guerry et al. 2015). Less progress has been made in integrating the ecosystem service concept into land management and policy decisions (Petz and van Oudehoven 2012, Sitas et al. 2014).

One of the main challenges has been the absence of a means of consistently understanding and quantifying how ecosystems provide services (de Groot et al. 2010). In order to capture the full dynamics of ecosystem service delivery, all of the components from production to benefit (and their links) need to be considered (Schröter et al. 2014, Jones et al. 2016). There have been a number of studies focused on quantifying the supply side (Egoh et al. 2008, Maes et al. 2012), as well as the demand side (Martin-Lopez et al. 2012, Casado-Arzuaga et al. 2013) of ecosystem services, with economic valuation a popular means of quantifying the role of ecosystems in supporting human well-being (Hein et al. 2006, Ghaley et al. 2014). Studies in which both the supply and demand of ecosystem services are assessed have however only recently gained momentum (Wolff et al. 2015).

The benefits derived from ecosystem services are rooted within a complex social-ecological system, influenced by interdependent drivers of demography, economic changes, environmental deterioration and changes in science and technology, behaviours and values (Nelson et al. 2006, Villamagna et al. 2013). Human societies are also not passive in the face of environmental change, and are able to operate, learn and change in order to increase or maintain the well-being of its members (Brown and Westaway 2011). Integrated studies dealing with both social and biophysical processes can better inform management interventions and improve the understanding of socio-ecological systems (Fischer et al. 2009, Laterra et al. 2016).

Efforts to maintain the capacity of watersheds to regulate floods have become a priority and an area receiving worldwide attention (Locatelli and Vignola 2009, Depietri et al. 2012). Watersheds have the ability to capture and store water during rainfall events, reducing the amount of runoff generated and lowering flood peaks through the ecosystem service of flood regulation (Le Maitre et al. 2014). Communities living in the downstream areas of watersheds are able to benefit from the flood regulation service through increased flood safety and reduced damages and losses (Logsdon and Chaubey 2013). The process of flood regulation is intricately linked with the terrestrial water cycle and is dependent on the features of the landscape (Brauman et al. 2007). By converting forest areas and wetlands into agricultural land and impermeable surfaces, humans have changed the way in which watersheds respond to rainfall events resulting in higher and earlier flood peaks (Baral et al. 2013, Nel et al. 2014). As human populations continue to concentrate in urban areas the need for adequate flood control and protection is steadily increasing (Radford and James 2013). By identifying and managing service providing areas which are the natural and biophysical areas providing the regulating service (Syrbe and Walz 2012), and linking them to service benefitting areas, which are the location where beneficiaries demand the regulating services (Syrbe and Walz 2012, Palomo et al. 2014a), sustained ecosystem service delivery can be enhanced. Visualising the connection between ecosystem service supply and demand is especially pertinent for the flood regulation service in which service flows are spatially dependent.

There are a lack of approaches and information to quantify and map supply and demand of flood regulating services in a linked and useful way. Much of the work is focused on quantifying potential supply of flood regulation (Laterra et al. 2012, Radford and James 2013, Koschke et al. 2014). The lag in the quantification of supply and demand of regulating services can be attributed to the fact that they are more challenging to quantify, as the benefits derived from the service are intangible and not directly used or consumed (Kumar and Wood 2010). The demand for regulating services is also not constant and is directly dependent on environmental conditions and pressures such as increased population and changes in land use (Smith et al. 2013).

Studies which have considered both supply and demand of flood regulation have used a risk based approach in which supply is quantified through hydrological modelling and the exposure of society or the vulnerability of assets to a potential disturbance is used as a proxy for demand (Nedkov and Burkhard 2012, Liquete et al. 2013, Stürck et al. 2014). A potential shortcoming in these approaches has been the exclusion of the wide range of socio-economic factors communities are exposed to and how they may interact to produce flood risk (Chapin et al. 2010, Bennett et al. 2015b). The determination of demand for flood regulation can benefit from a more comprehensive view of vulnerability such as the view proposed by Turner et al. (2013). In this approach vulnerability is predicted based on the synergy between human and biophysical subsystems, sensitivity to exposure and the system's capacity to cope or respond to stressors. Exposure refers to the degree to which a region, resource or group are subject to natural hazards, whereas a hazard is "an event or physical condition that has the potential to cause fatalities, property and infrastructure damage, agricultural loss and damage to the environment" (Bahauddin and Uddin 2012). The chapter sets out to spatially define the actual used or demanded contribution of ecosystems in providing flood regulation (final flood regulation service) to downstream communities in a flood prone region in South Africa by using an integrated people centred approach.

5.3 Method

The unit of analysis for the study was set as the watershed, which is the natural drainage area in which rainfall converges into a single point and drains in a waterbody, wetland or lake. The watershed was further stratified into municipal wards, as this is the level at which socio-demographic data was collected in the national census (Statistics South Africa 2011). The method is based on the analysis of bio-geophysical GIS data and national census data, both of which are widely available and updated on a regular basis. The advantage of using this data is that urban population growth and the supply and demand of services are always in flux and therefore regular updates on data will ensure that changes in the system can be captured over time. The method consists of two components: (1) determining the spatial location of flood regulation supply areas using the risk based model Sensitive Watershed Integrated Modelling and Analysis Platform (SCIMAP); (2) estimating and mapping the final regulating service through relating flood hazard, exposure and social and economic resilience of downstream areas.

5.3.1 Case study watersheds

The study was carried out in two urban watersheds situated along the southern Cape coast of South Africa (Fig. 5.1). The George (Fig. 5.1) and Knysna (Fig. 5.2) watersheds form part of what is known as the "Garden Route", so called due to its rich biodiversity and pristine natural landscape (Vromans et al. 2010). The area is characterised by a rugged terrain, with numerous river valleys, coastal cliffs, afro-mountain forests, bays and beaches. These natural features are major draw cards for tourists, retirees and job seekers. Both watersheds have been affected by floods in the last decade with significant impacts to tourism, economic activities, and local infrastructure (Mélice and Reason 2007, Tempelhoff et al. 2009).

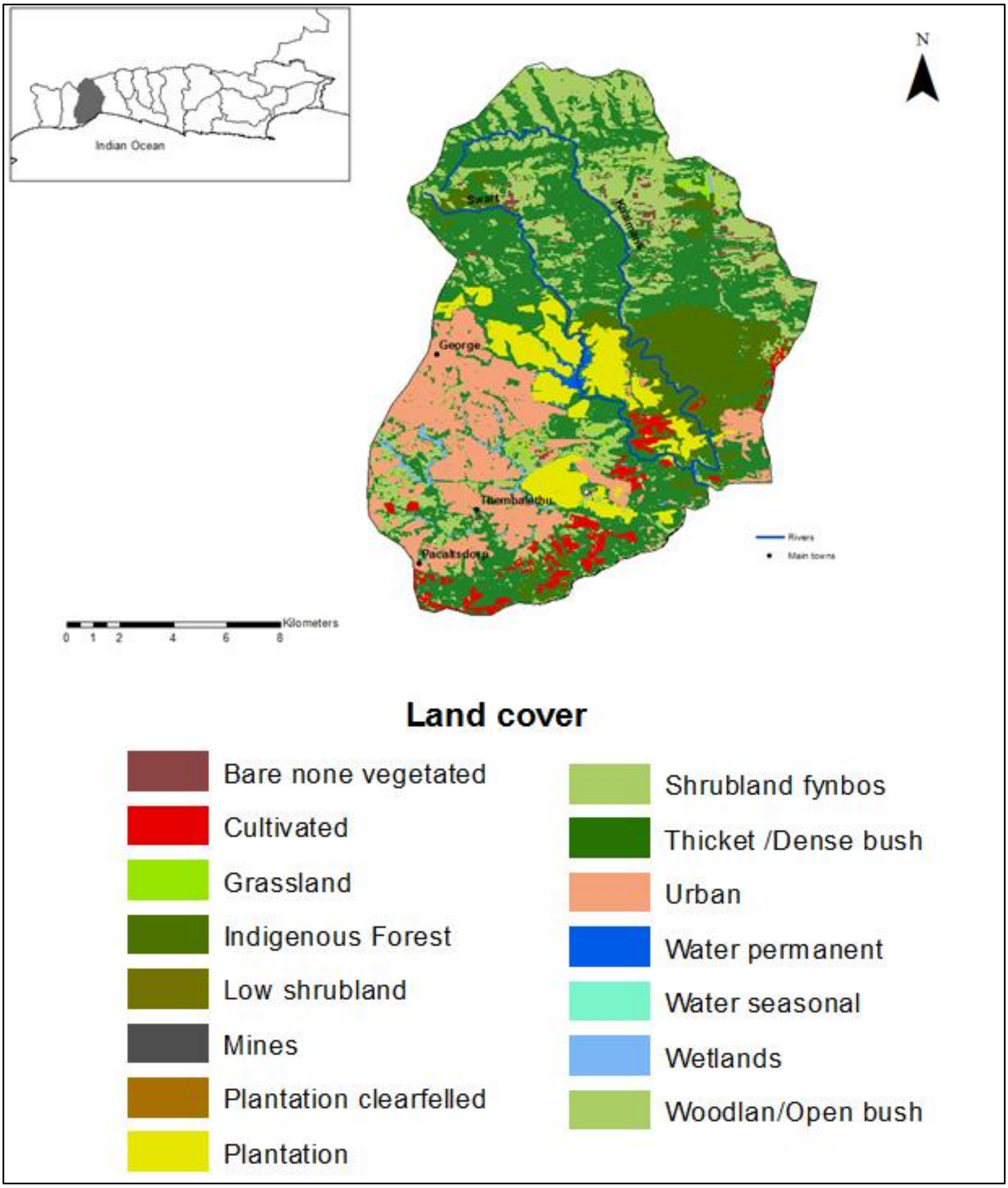

Figure 5.1: George watershed showing its current land cover (NLC, 2014), main towns as well as position within the Garden Route catchments.

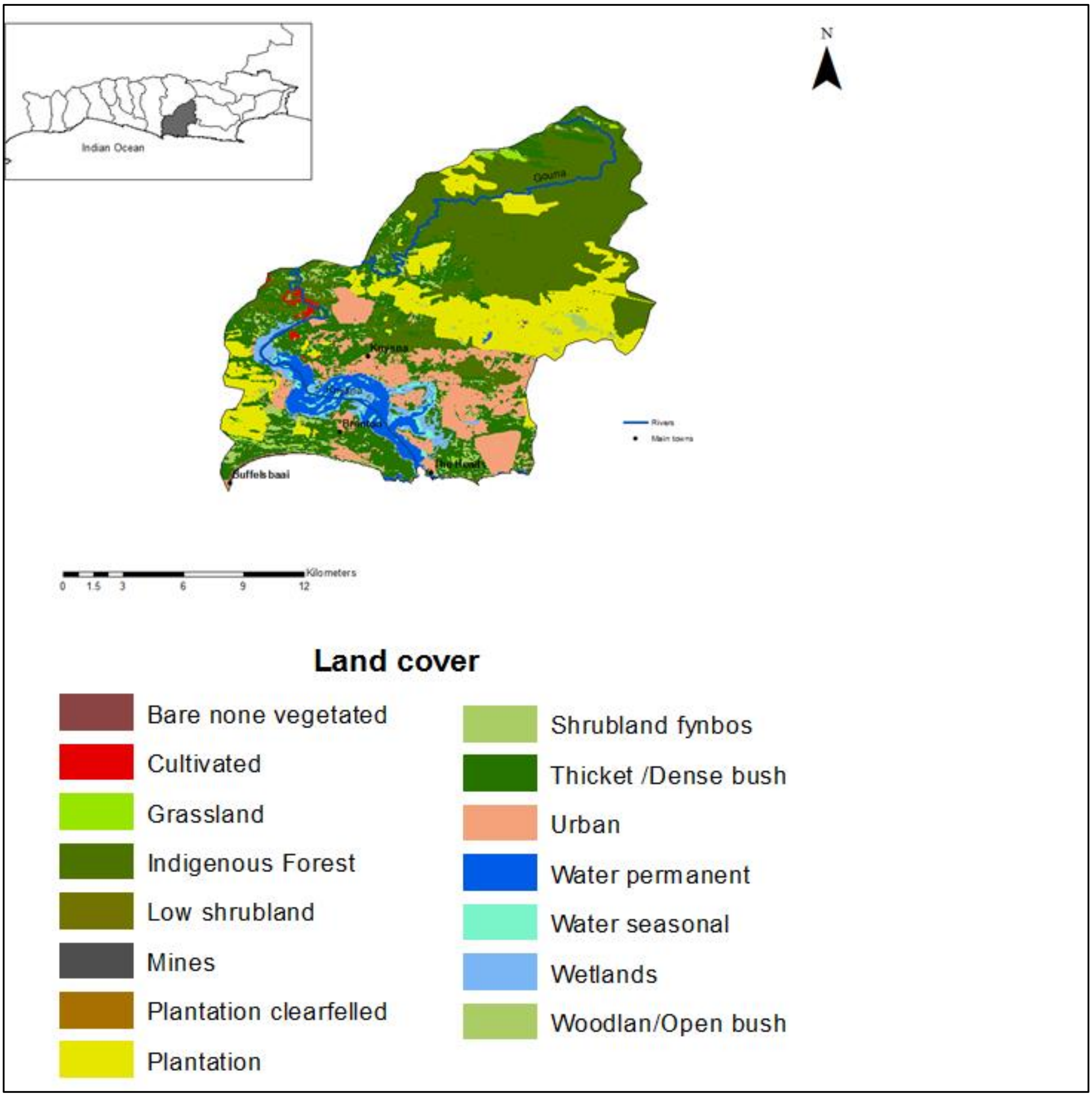

Figure 5.2: Knysna watershed showing its current land covers (NLC, 2014), towns as well as position within the Garden Route catchments.,

The watersheds were chosen as each watershed has a distinct social-ecological context with residents settling in the respective watersheds for different reasons. Comparing the demand for flood regulation in the two watersheds can provide further insights into how demands for flood regulation are generated in the watersheds. The George watershed occupies an area of 109 km^2 and has a population of approximately 44 610 people. It is what is known as a regional urban centre, and is the hub for jobs and lifestyle, with the highest concentration of work opportunities, health services and education, business and cultural facilities in the region (Eden District Municipality 2009). Rapid urban growth due to both local population growth and in-migration has placed significant pressure on the provision of affordable housing and services in the watershed. As a result, new arrivals from people in lower income groups have built homes in topographically inappropriate areas in informal peri-urban areas subjected to flooding. The informal settlements lack adequate municipal services such as water supply, storm water and road infrastructure, waste collection, medical services and park space, placing them at higher risk during a flood event (RADAR 2010). The Knysna watershed occupies an area of 202 km^2 and has a population of approximately 17 784 people. The Knysna watershed is what is known as a major urban centre and plays a critical role in the economic performance of the region (Eden District Municipality 2009). It is home to the Knysna estuary, which is one of the largest estuaries along the southern Cape coast of South Africa (Maree 2010). The upper regions of the watershed are covered in protected afro-montane forest and indigenous fynbos (Marker 2003). Property in the Knysna watershed is highly desirable, with areas adjacent to the estuary densely settled with both exclusive residential developments and informal settlements (Marker 2003). Living in such close proximity to the estuary puts residents at increased risk of flooding. Exposure to the hazard is however offset by coupled locational benefits such as livelihood opportunities, accessibility and coastal amenities.

5.3.2 Hydrological modelling

The Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) is a physically based risk model with an explicit use of hydrological connectivity developed by the Durham and Lancaster Universities along with the British Environment Agency (http://www.scimap.org.uk/). The model was initially developed to identify sources of diffuse pollution (Reaney et al. 2011), but has been adapted in Chapter 3 to identify flood receiving areas. The model outputs are used to predict the capacity to provide flood regulation as well as to predict hazard areas which are one of the components used to calculate demand for flood regulation. The model inputs include topographical data, rainfall data, soils data and land cover data. A digital elevation model (DEM) with 20m resolution was used for topographical data (Chief Directorate Surveys and Mapping 2002). The national land cover map of South Africa was used to obtain land cover data (Van den Berg et al. 2008). To account for extreme rainfall, design rainfall data for a 50 year return period was taken from the South African Atlas of Climatology and Agrohydrology (Schulze 2008). Soil data for construction of a runoff curve number was obtained from the Soils and Terrain Digital Terrain Digital Database (SOTER) for South Africa (Dijkshoorn 2003). The model framework consists of five steps which include (1) the estimation of runoff generation risk (2) determination of a connection probability for runoff generated (3) the combination of the generation probability and connection probability to produce a runoff generating potential (4) rooting the runoff generating potential through the river network to get a risk concentration and (5) transformation of the risk loading to a flood risk concentration.

5.3.3 Flood regulation supply

Supply was mapped based on the capacity of the watersheds to generate runoff and the hydrological connectivity of the watershed. A flood generating risk map was generated in step 1 of the SCIMAP model based on the energy available to produce runoff and the resistance to runoff generation. The energy available to produce runoff was determined based on the local slope and the upslope contributing area determined from rainfall and topographic data derived from the DEM. To account for resistance to runoff generation a land cover weighting, in the form of a runoff curve number (CN) was used. The CN number is a function of land cover type and hydrologic soil group and gives an indication of the permeability of the land in a watershed (Laura et al. 2011). In step 2 the connection probability of runoff produced is determined based on flow pathways, slope and upslope contributing area. The generation and connection probability is combined to produce the flood generation potential map. This map is used to determine the flood regulation supply of the watersheds. Classes of high, medium and low were determined using a Jenks natural breaks classification in ArcGIS 10.3 (Environmental Systems Research Institute 2015). Using the landscape classification of (Syrbe and Walz 2012) areas with high flood generating potential were classified as service providing areas, areas with medium flood generating potential were classified as service connecting areas, and areas with low flood generating potential were classified as service benefitting areas.

5.3.4 Final flood regulation service

The final flood regulating service was determined by relating the flood hazard and level of flood exposure of downstream communities to their social and ecological resilience. To determine the flood hazard of areas downstream of the study watersheds, the flood receiving areas map generated with the SCIMAP model in step 5 was used. A mean flood hazard value for each ward was generated using the ArcGIS zonal statistics tool (Environmental Systems Research Institute 2015). The number of people per ward was used as a proxy for exposure to flooding. Due to the people-centred focus of this study, it is assumed that the higher the number of people in a ward, the higher the level of exposure. Further, to gain insight into the ability of flood exposed communities to respond to flood impacts, a composite social and economic resilience index was constructed. The variables included in the analysis have previously been identified (through a Principal Component Analysis (PCA) in Chapter 4) as contributing to the social and economic resilience of the George and Knysna watersheds. The social component captures the internal strengths and resources within communities to deal with floods and suggests that communities with higher levels of education, access to a telephone, those who have been living in the area for a period of time, are employed and have access to a vehicle display higher social resilience (Table 5.1). The economic resilience component measures the resources available to the community and includes the availability of water infrastructure, level of income earned, employment equity, type of housing, and housing capital (Table 5.1). Data used to construct the index were obtained from the 2011 Census of South Africa and was collated at the ward level (Statistics South Africa 2011). To standardise the data, a min-max normalisation technique was performed on all variables (Priddy and Keller 2005). Using the aggregation method proposed by Cutter et al.,(2010), both a social and economic resilience index were calculated by using the arithmetic mean of the respective social and economic variables for each ward. Due to the absence of information on importance and weighting of these various scores, the final flood regulation service was determined by using a simple equation in which a ward's flood regulation flow was determined as the difference between the *flood hazard* and *flood exposure of the ward and* the *social and economic resilience* of the ward's communities. Classes of high, medium and low flood regulation flow were determined using a Jenks natural breaks classification in ArcGIS 10.3 (Environmental Systems Research Institute 2015.)

Table 5.1: Description of variables selected for Social and Economic Resilience Index with justification for use.

Variable	Description	Justification
Social component		
Education	% population with a high school diploma.	(Tierney and Bruneau 2007, Norris et al. 2008)
Employment	% population employed.	(Morrow 1999)
Place attachment	% population with ten years+ residence.	(Maclean et al. 2014)
Transportation Access	% population with a vehicle.	(Morrow 2008)
Communication capacity	% population with a cell phone.	(Sutton et al. 2008)
Economic component		
Housing capital	Percent home-ownership	(Morrow 1999)
Housing type	Percent formal housing	(Flanagan et al. 2011)
Income	Percentage pop earning > $400	(Morrow 1999)
Employment equity	% female labour.	(Euwals et al. 2010)
Water infrastructure	% piped water % flush toilets.	(Abdallah and Burham 2000)

5.4 Results

5.4.1 Flood regulation supply

Figure 5.2 shows the potential supply of regulating services as determined by the flood generating potential map of the George (Fig. 5.3(a)) and Knysna (Fig 5.3(b)) watersheds. In the George watershed the service providing area constitute 37% of the watershed. Runoff is largely generated in the upper mountainous part of the watershed and along the coast. The service connecting area constitutes 27% of the watershed and consists of indigenous forest, forest plantations, cultivated areas, thicket or dense bush and grassland. Service benefitting area constitutes 36% of the watershed. These areas are located in urban areas west of the watershed and along the south-eastern coastline. In the Knysna watershed (Fig. 5.3(b) service providing areas make up 20% of the watershed. These areas comprise urban areas, plantations and thicket or dense bush. Service connecting areas make up 45% of the watershed, and consist of indigenous forests, forest plantations and thicket or dense bush. The service benefitting areas constitute 35% of the watershed, of which 12% comprise the Knysna Estuary which serves a flood attenuation function in the watershed.

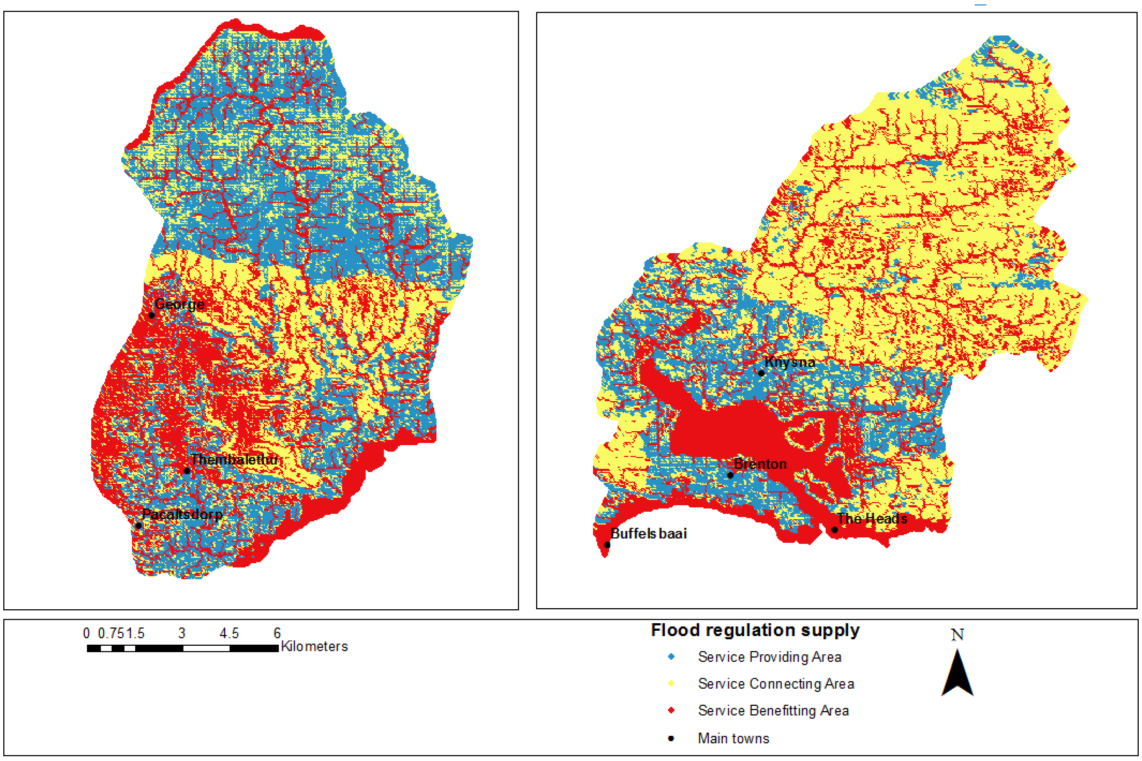

Figure 5.3: Flood regulation potential of the a) George catchment and b) Knysna catchments.

5.4.2 Flood regulation demand

Figure 5.4 shows the hazard areas for the George watershed as determined by the SCIMAP model. Results show 80% of the George watershed has a high susceptibility to surface water flooding, whilst 18% has medium susceptibility (Fig. 5.4 (a)). Areas with low susceptibility make up 0.6% of the watershed. Wards with high susceptibility to surface water flooding are located in the northern and southern regions of the watershed, whilst wards in the north-west of the watershed surrounding urban areas have lower flood susceptibility. Figure 5.4 (b) provides an overview of the flood exposure in the George watershed. Wards with the highest exposure are located in the city centre north-west of the watershed, as well as the peri-urban wards to the south and the ward to the north of the watershed containing a coastal resort town. Figure 5.4 (c) shows the spatial distribution of social resilience within the George watershed. Wards with high social resilience scores are generally concentrated around the city centre and the established sub-urban wards north of the watershed. Areas of lower social resilience are located in the sub-urban and peri-urban wards south-east of the watershed. The spatial distribution of economic resilience is shown in Figure 5.4 (d). The highest economic resilience scores are located in the wards surrounding the city centre and sub-urban wards. Lower economic resilience scores are located within the peri-urban wards of the watershed.

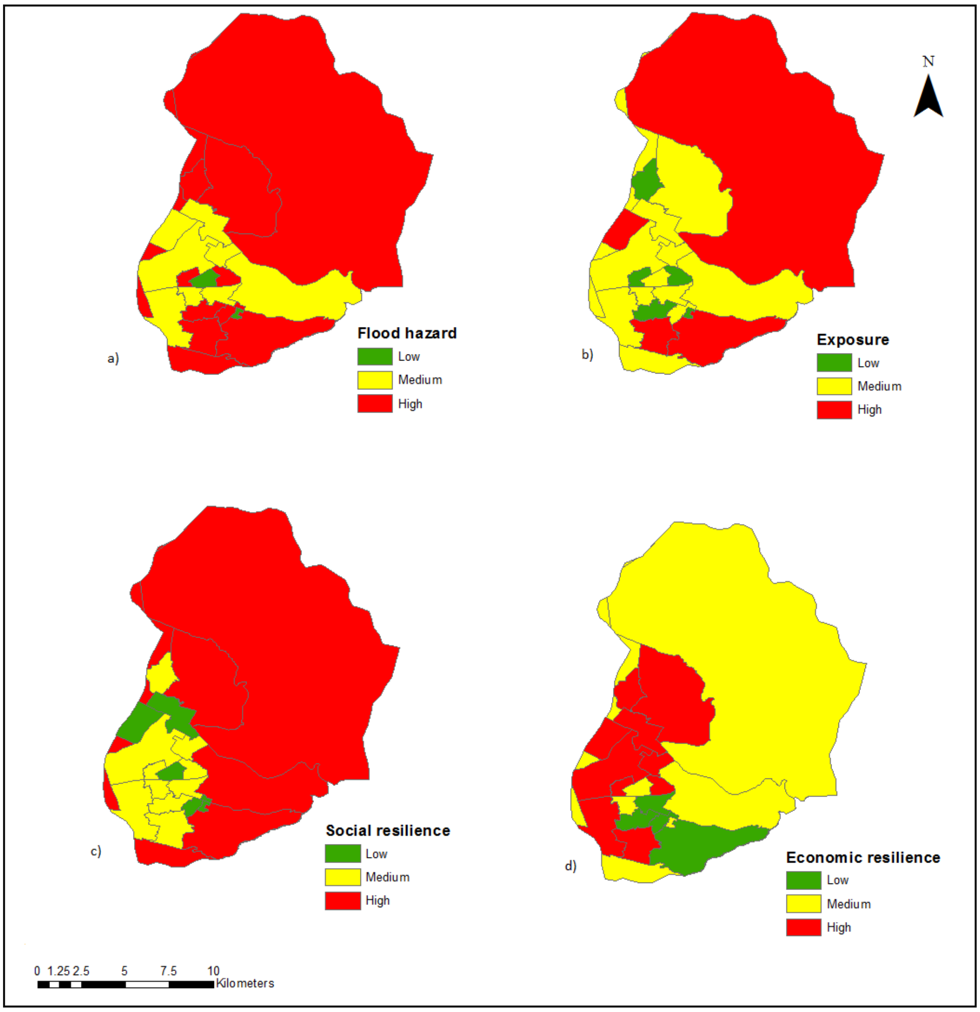

Figure 5.4: Spatial distribution of the (a) flood receiving areas,(b) exposure and (c) social and (d) economic resilience for the George watershed per municipal ward. Results have been classified into classes of low, medium and high using natural breaks.

Figure 5.5 (a) shows the hazard areas within the Knysna watershed. About 12% of the watershed is highly susceptible to surface water flooding, whilst 77% has a medium susceptibility. Areas with low flood susceptibility make up 11% of the watershed. Wards with a high susceptibility to surface water flooding are located north of the estuary, whilst the wards south-east of the estuary have lower susceptibility. The flood exposure within the Knysna watershed is shown in Figure 5.5(b). Wards with the highest exposure are located in the peri-urban wards in the north of the watershed, with medium exposure in the wards above the estuary and lowest exposure in the wards located at the top and bottom of the watershed. Figure 5.5(c) shows the spatial distribution of social resilience in the Knysna watershed. Areas with high social resilience are located immediately adjacent to the estuary, whilst wards further north of the watershed have generally lower social resilience. The spatial distribution of economic resilience is shown in Figure 5. 5 (d). Areas with high economic resilience are located south-east of the estuary, whilst the wards north of the watershed have lower economic resilience.

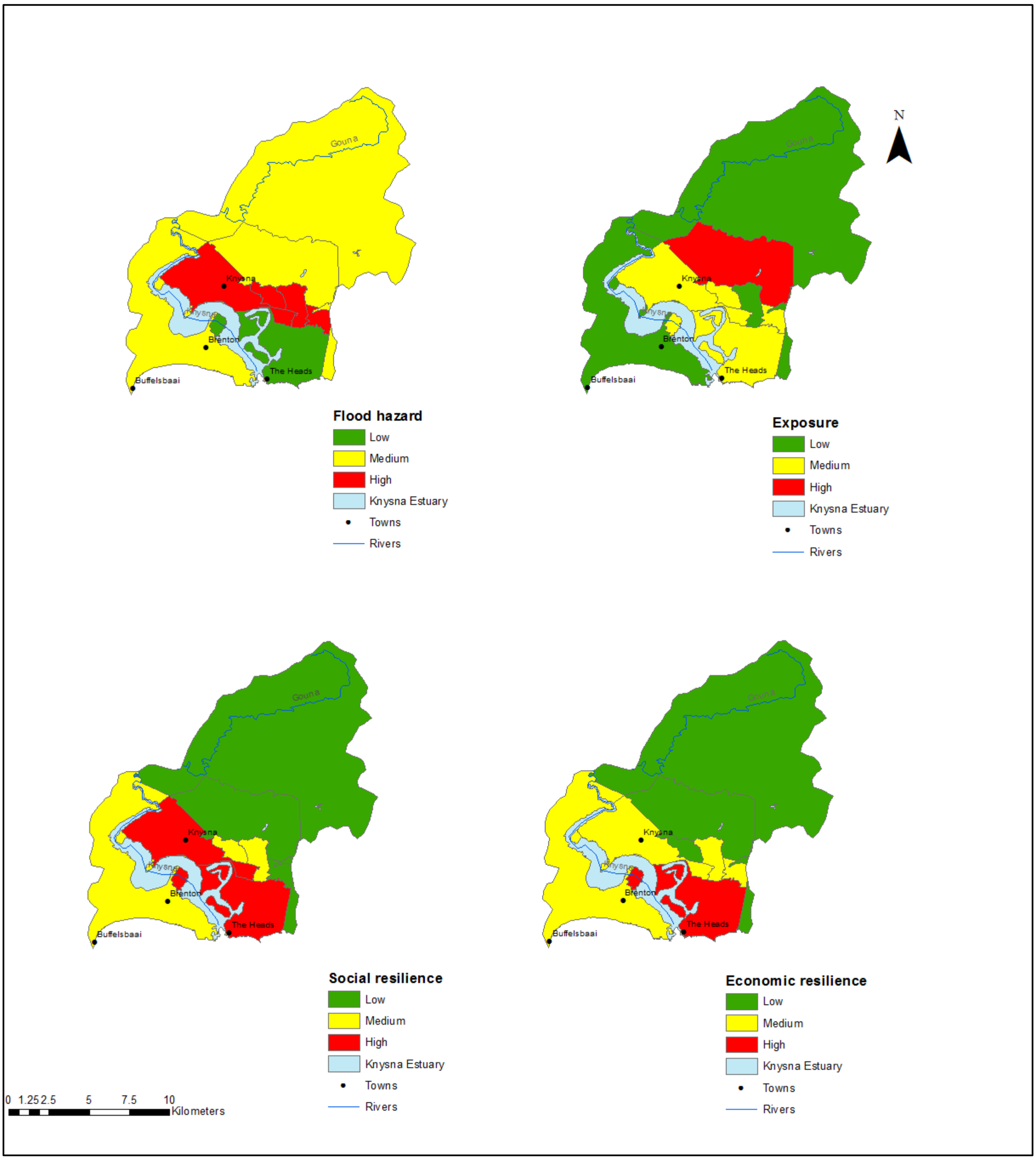

Figure 5.5: Spatial distribution of the (a) flood hazard, (b) exposure, (c) social and (d) economic resilience of the Knysna catchments per municipal ward. Results have been classified into classes of low, medium and high using natural breaks.

The final flood regulation service, which is the actually used or demanded contributions of ecosystems in the George watershed, is shown in Figure 5.6. Wards with a high demand for flood regulation comprise 75% of the George watershed, whilst 9% of the watershed has a medium demand. Wards with a low demand for flood regulation make up 16% of the watershed. High demand for flood regulation is located in the outer wards east of the watershed. The sub-urban wards south of the city centre and the coastal village at the bottom of the watershed have a medium demand for flood regulation. Areas with lower demand for flood regulation are located in the city centre, and established sub- urban area north of the city centre.

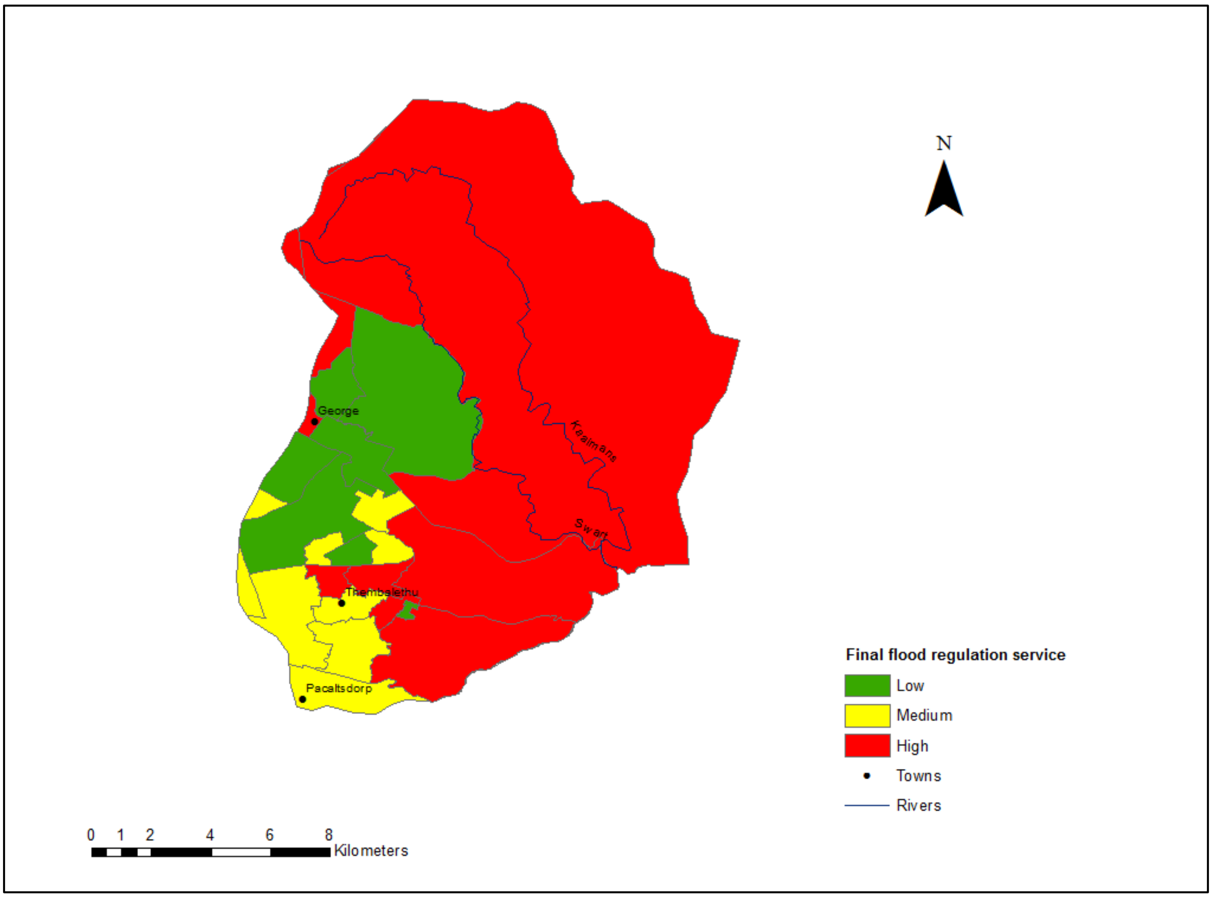

Figure 5.6: Final flood regulation service in George watershed. Results have been classified into low, medium and high based on natural breaks.

The spatial distribution of the final flood regulation service for the Knysna watershed is shown in Figure 5.7. Wards with a high demand for flood regulation comprise 59% of the watershed, whilst 29% of wards have a medium demand, and 12% of wards have a lower demand for flood regulation. Wards with high demand are located in the peri-urban areas in the middle of the watershed. The wards in the north of the watershed and those adjacent to the estuary have medium flood demand, whilst wards south-east and below the estuary have lower demand for flood regulation.

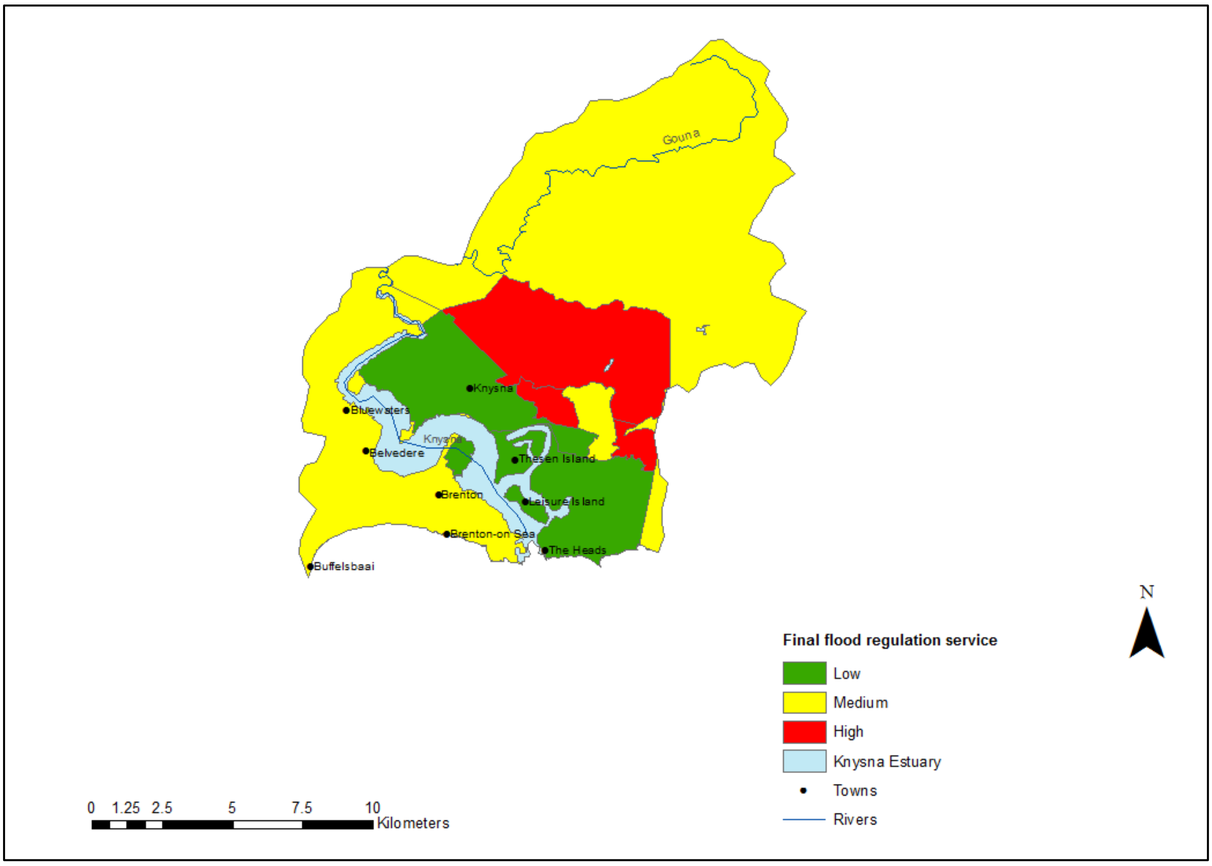

Figure 5.7: Final flood regulation service in Knysna watershed. Results have been classified into low, medium and high based on Jenks natural breaks classification.

5.5 Discussion

This paper introduces and illustrates an approach to characterise and spatially connect regulating ecosystem service flows from supply to demand. What sets the approach apart from previous studies is that rather than focusing on the supply and demand of services separately, the assessment looks at the relationship between them. Studying the interconnections within social-ecological systems can highlight the trade-offs between land use activities and the provision of regulating services (Garcia-Llorente et al. 2015). This is especially important for regulating services which are largely invisible until changes in ecological function occur (Outeiro and Villasante 2013, Vidal-Abarca et al. 2014). In a complex and heterogeneous social-ecological system, changes in the system can affect people and places unequally and cause different types of outcomes (de Oliveira Mendes 2009, Lorenz 2010). Investigating the interrelationship between ecological and social components can assist in defining appropriate management decisions and response strategies that can build the necessary social and ecological adaptive capacity needed to continue to enhance human well-being.

To illustrate the variation in supply and how humans shape the use and demand for regulating services, the approach was applied in two urban watersheds. The two watersheds chosen as case studies reflect global coastal urbanisation trends. Both watersheds are situated along the coast and therefore are highly popular for human habitation, but like many coastal areas in the developing world are vulnerable to floods (Craig and Ruhl 2010, Ahammad et al. 2013). Due to the job opportunities and scenic beauty provided by coastal watersheds they continue to attract people wanting to settle in the area, while at the same time climate change will continue to increase the frequency and uncertainty of flood events (Craig and Ruhl 2010). Management action should therefore aim to provide sustainable supply of flood regulation which supports socio-economic development and well-being of flood affected communities. One such lens on priority management areas is related to the high levels of inequality in the region that leave many unequally vulnerable to flooding events, with little capacity to adapt and continue to develop during and after flood events. Mapping the needs of such populations through a flood demand approach is vital.

5.5.1 Supply of flood regulation services in the Garden Route watersheds

The potential of the study areas to provide flood regulation was investigated through the use of the SCIMAP model. Both watersheds have a rich natural resource base, with upper watersheds covered in largely intact indigenous forests and soils that are able to reduce runoff, and thereby provide a buffering system to downstream areas during small scale rainfall events. Due to rapid growth of agricultural areas and urban development, it is nearly impossible to manage and conserve all of these areas. By linking supply areas to the downstream benefitting areas of the watershed, areas directly linked to high demand can be conserved to ensure a sustainable supply of the flood regulation service (Syrbe and Walz 2012). The George watershed is highly responsive to rainfall with large parts of the watershed predicted to be service providing areas. The indigenous forest, thicket and forest plantations in the upper watershed are able to attenuate runoff to provide flood regulation to areas west of the watershed. In the Knysna watershed, communities are located directly on the service providing areas of the watershed. The estuary serves a buffering function within the watershed and is able to store and attenuate runoff generated during rainfall events. Management actions should therefore ensure that anthropogenic pressure and disturbances in the watershed, but especially in the areas surrounding the estuary, are kept to a minimum.

5.5.2 Demand and use of the final flood regulating service in the Garden Route watersheds

Relating flood hazard with level of exposure and the resilience of flood affected communities allowed for the identification of underlying heterogeneity in the use and demand for flood regulation in the study watersheds. The distribution of hazard areas is extensive in the George watershed where wards in both upper and lower parts of the watershed are located in areas highly susceptible to surface water flooding. The wards containing the city centre, peri-urban areas, and the coastal resort town north of the watershed were identified as having the highest level of exposure. A clear spatial distinction was shown in the resilience of residents of the watershed with generally high social and ecological resilience in the urban wards, and low social and economic resilience in the peri-urban wards. These latter wards are the location of many of informal settlements where communities have low social and economic resources and resilience. When these data layers are combined, it highlights those populations in highly hazardous and exposed areas, with low resilience, and little or no protection from a flood event, areas where flood regulation provided by the connecting watershed is essential. The spatial distribution of the final flood regulation service suggests that the demand and use of the service is highly influenced by topography and location in the watershed. Urban expansion into marginal areas of the watershed has hardened surfaces, and thereby increased surface runoff and the demand for flood regulation in the peri-urban wards.

In the Knysna watershed susceptibility to surface water flooding is associated with proximity to the estuary, with the highest susceptibility in areas located north of the estuary. A lower demand or use for flood regulation was identified in wards where flood susceptibility is high, exposure levels are moderate, and where the communities at risk are sufficiently resilient and prepared for a flood event. Wards on the periphery of the main town had higher use or demand for flood regulation. Despite having moderate flood susceptibility, they had high levels of exposure, with low social and economic resilience. By considering both ecological and social aspects of ecosystem service delivery a clearer perspective on the dynamics of the study watershed was garnered, allowing a refinement of the larger areas with high flood hazards. Where residents of the Knysna watershed are able to offset their risk with high social and economic resilience, poorer communities in both the George and Knysna watersheds are likely to suffer greater losses due to their lower adaptive and coping capacity. These wards should be prioritised, with mitigation measures aimed at increasing resilience through upgrading infrastructure and ensuring adequate housing, as well as targeted management of the flood regulation areas of relevance.

5.5.3 Strengths and limitations of the approach

There are many ways to map demand and use for ecosystem services, and as regulating services are underexplored in the demand side mapping, this is an area of innovation and new methods. The proposed method builds on thinking in flood vulnerability and incorporates landscape connections from supply to demand areas. It also takes a much wider approach to include socio, economic and ecological inputs, as well as the adaptive and transformative capacity from a resilience perspective to derive the actually used or demanded flood regulation service. It adopts a people centred approach which acknowledges the inequality and development challenges experienced by many developing countries. The approach is however flexible, and could include other aspects of exposure beyond people, such as land or urban assets (Sanders and Phillipson 2003), as well as other components of resilience such as infrastructure and institutional resilience (Kotzee and Reyers 2016)(Chapter4). Resilience is a dynamic process which is dependent on antecedent conditions, disaster severity, and external factors which change over space and time (Cutter et al. 2008). Assessments are also dependent on what values are assessed (resilience of what) and underlying determinants of resilience considered (resilience to what) (Carpenter et al. 2001). However, due to data and methodological constraints, a static depiction of resilience is presented here. Ideally we would want to compare resilience of communities over time and space to get an accurate depiction of resilience. In order to integrate ecological and social aspects

5.5.4 Challenges in mapping demand for regulating services

Mapping the demand for flood regulation (and in fact many regulating services) is complex due to the multitude of factors affecting demand e.g. number of people, exposure of those people, vulnerability, resilience etc., as well as the many other aspects one would want to consider like land or buildings (if you were an insurer or a public official). Combining these factors into one model or map is challenging and risks hiding important variables and heterogeneity. In this approach the sub-components are rather kept separate with factors explored with the use of simple mathematical function that highlights the relationship between components and identifies areas with a high priority for demand. This allows for disaggregation, to explore underlying features, as well as the regular updating of new data to account for the dynamic nature of the social and ecological components of these areas. The approach can however benefit from more sophisticated analyses. The incorporation of models and spatial analyses able to support aspects of planning such as scenario analyses and urban planning processes would be useful ways forwards. All services are dynamic, but the demand for regulating services is especially so. There is a need for regularly updated data, but also for approaches and management that can cope with uncertainty, spatial and temporal disconnects and the invisibility of regulating services associated with natural hazards.

5.6 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field*. *Ecosystem*

Management Series no. 9 .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward.

2015a. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing

ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and*

Resources 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral*

Research 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O’Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth*

Surface Processes and Landforms 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland's valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

Garen, D. C., and D. S. Moore. 2005. "Curve number hydrology in water quality modeling: Uses, abuses, and future directions," - Reply to discussion. *Journal of the American Water Resources Association* 41(6):1493–1494.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in

integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D.

Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors).

Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale

environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature’s benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for

a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services.

Progress in Physical Geography 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the

case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity* 12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*

8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O'Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O'Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of*

Disaster Risk Reduction 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*.

Garden. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance.

Ecological Modelling 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth 's climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-

Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E. 2008. *South African atlas of climatology and agrohydrology*. Pretoria.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the “regulating” services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A*

multi-stakeholder approach to targeted intervention in selected municipalities. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International …*.

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB*.

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in

the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems : A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 6

Synthesis

6.1 Synthesis

Although flooding is not a new phenomenon, the risks it poses have increased significantly in recent years, prompting the use of new ways to effectively manage flood events. The main factors cited for the increase in risk are the intensification of flood producing weather events, population pressure and development within flood prone areas (Hümann et al., 2011). Management priorities are expanding from largely investing in flood control infrastructure, to looking at ways in which the impact on communities and the exposure to flood risk can be reduced (Moser, 2010; Preston et al., 2011). The research presented here focuses on developing approaches able to inform a more integrated flood management which make use of readily available data sources. The approaches, models and tools which have been developed and adapted were tested using regionally available data in South Africa to explore their applicability in areas where data for process-based models and the capacity to interpret model outputs may be limited. The overall objective of this thesis was to develop and pilot a flood resilience management strategy based on improved systems approaches and knowledge on floods, flood regulation services and impacts on people and infrastructure. This chapter returns to the objectives set out in chapter 1 and discusses the main findings and contributions from the individual chapters.

6.1.1 Summary of findings

Sub-objective 1*: Gain a better understanding of the state of knowledge on regulating services by reviewing progress in research of regulating services since the Millennium Ecosystem Assessment, with a particular focus on progress in their assessment and quantification (Chapter 2).*

Chapter 2 focuses on an understudied, yet essential area of ecosystem services namely, regulating services. Due to their ability to moderate the flow of energy and materials, regulating services are crucial in rapidly changing landscapes. Despite their apparent value regulating have been rapidly modified, converted, over-exploited and degraded over the last century. However, due to the largely invisible, slow changing and multi-scale nature of regulating services they are the least understood and the most at risk from human activities. In this first ever-comprehensive review of regulating services the advances and remaining gaps in the assessment of regulating services is shown. The review highlights biases in services studied, especially gaps in acknowledging the complexity of regulating services such as water regulation and climate regulation. The review shows that majority of research to date has been conducted in developed regions such as North America, Europe and Eastern Asia, with fewer studies in less developed regions of Africa, Central America and Asia. Assessments and quantification of regulating services has also tended to adopt a narrow range of approaches and disciplines resulting in predominantly quantitative assessments done by natural scientists. The review also found that the majority of assessments were conducted in agro-ecosystems and forests, with studies on estuarine and coastal as well as marine habitats mostly lacking. Research tended to be focused on either patch or regional scales with very few studies conducted at multiple scales. This is a point of concern as regulating services are produced at multiple scales. This may be due to the tools not being available at the moment. From these results it appears that research on assessing regulating services would benefit from more integrated and interdisciplinary approaches able to link the social and ecological components of regulating services, as well as their links to human well-being and governance (Daw et al. 2011).

Sub-objective 2*: Develop a clearer understanding of the flood generation process and how it can be managed, in especially under-resourced areas (Chapter 3).*

In Chapter 3, the potential use of the Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) to capture, assess and identify flood receiving areas was tested. The approach was adapted and applied in the Garden Route watersheds to illustrate how it can be used to provide a better conceptual understanding of the physical processes in a watershed and their underlying drivers. The aim of the approach was to move from traditional flood management which have focused on river training, and construction of embankments to a management approach which uses a systemic understanding of both structural and functional dynamics of a watershed. Moreover, as was highlighted in Chapter 2, there is a need for approaches which can be applied in developing countries where there might be a lack of resources. A simple watershed scale model which uses readily available datasets was therefore chosen to model flood receiving areas. In addition to the final output of a flood receiving areas map, model outputs consisted of a network index; a runoff generating potential map and a stream power index, all of which contributes towards a better understanding of how underlying watershed properties interact to drive flood generation. Rather than an empirical understanding, the model provides a process-based understanding, which allows managers to interpret the system and predict when, where and how to intervene in catchment processes to ensure successful catchment management (Bracken et al. 2013). The approach shows great potential as a decision support tool for improved flood management and is intended to be used in the preliminary stages of a study to prioritise areas in the landscape where future resources, time and expertise should be focused.

Sub-objective 3: *To develop a practical approach to measure resilience of a system to a flood based on resilience theory and insight (Chapter 4).*

In chapter 4, a multi-dimensional approach to measuring resilience was developed and piloted. The study demonstrates the possibility of spatially depicting and communicating flood resilience values in a readily calculated, repeatable and transparent manner using a composite index approach. The ease of use, transparency and replicability of the approach was especially important as it was felt that previous models and tools designed to measure resilience have had limited uptake in social-ecological systems management, due to the absence of these criteria (Nyström et al. 2008, Malone and Brenkert 2008). What sets the approach apart from other disaster resilience indices (Cutter et al. 2010, 2014) is firstly, that it looks specifically at flood resilience and secondly, that it allows for the disaggregation of the underlying components of social, ecological, and economic and infrastructure resilience.

Sub-objective 4*: Develop an integrated systems approach to spatially define and link the supply and demand of the flood regulating service (Chapter 5).*

In chapter 5 an approach to characterise and spatially connect the flood regulating ecosystem service flows from supply to demand was introduced and illustrated. The approach included the use of a resilience perspective in which a people centred priority was adopted to fit the inequality and development challenges experienced by many developing countries. What sets the approach apart from previous studies is that rather than focusing on the supply and demand of services separately, the assessment looks at the relationship between them. The proposed method builds on from the thinking in flood vulnerability and incorporates landscape connections from supply to demand areas. It also takes a much wider approach to include socio, economic and ecological inputs, as well as the adaptive and transformative capacity from a resilience perspective.

6.2 Overall insights

A resilient community is described by Schelfaut et al. (2011) as a community that is knowledgeable and aware of risk, is well prepared, responds well when a flood occurs, and is able to recover more quickly from disasters. The studies carried out in this dissertation make a valuable contribution in developing management strategies able to build flood resilient communities. This contribution is shown firstly, in the identification of flood receiving areas. This forms a fundamental component of a flood management strategy, allowing for the anticipation of possible impacts and the prioritisation of resources. Secondly, the contribution focuses on developing a flood resilience index able to identify the main elements of flood resilience within a community which can be used to recognize the components which lead to improved resilience and to set targets to improve the resilience of low scoring areas. And thirdly, the research enables spatially connecting flood regulating ecosystem service flows from supply to demand, to facilitate management actions aimed at ensuring the sustainable supply of the flood regulating service. The findings presented are the result of many hours of learning, of adapting and developing new approaches for measuring floods, flood regulation and resilience to improve flood risk management; in doing this research the following general insights were garnered.

6.2.1 Data Constraints

The research was conducted in the Garden Route municipalities which forms part of the Eden District, a relatively well resourced municipality in South Africa. In general the topographic, historical flood and land cover data required for flood modelling analysis in South -Africa was very limited. Historical flood data plays a very important role in the calibration and validation of flood models, but no sources (data flood maps, dated photographs, flood marks etc.) of historical data exist for the study area. Due to the dynamic nature of floods, these data need to be continuously updated. These data constraints were circumvented by using publicly available data to ensure that the final results could be regularly updated with new data, validated, reproduced and replicated. The use of publicly available does put some constraints on the type of assessments that can be done. As with many indices, secondary data in the form of the national census data were largely used to construct the flood resilience index (Chakraborty et al. 2005, Hahn et al. 2009). Impacts of floods are however experienced at finer scales than the scale at which data for census are collected (Nelson et al.

2015). It is however the scales at which decisions are made in terms of disaster management, and could therefore be used to prioritise areas with low resilience.

6.2.2 Understanding the "social" in social-ecological systems

The concepts explored in this dissertation, such as the quantification of flood resilience, and spatially linking flood regulation service from supply to demand are aimed at informing better management and policies. In doing so the research needed to move beyond the traditional separation of social and ecological systems towards coupled social-ecological systems. Due to the scale at which research was conducted, and the use of secondary data, some of the heterogeneity and social complexity of social systems were lost. Several assumptions were also made with regard to human adaptive capacity. The research could benefit from understanding, insights and critiques gained from other disciplines such as social anthropology and political ecology (Cote and Nightingale 2012, Fabinyi et al. 2014).

6.3 Future Research

A central lesson of this work is the recognition that a focus limited to a single stressor (e.g. floods), is insufficient for understanding impacts and responses of complex social-ecological systems. More integrated approaches are needed to make explicit the links and feedbacks through which social and ecological systems interact. To do so, more integrated and interdisciplinary approaches are required.

There is a need for regularly updated data, but also for approaches and management that can cope with uncertainty. The development of metrics and models able to deal with spatial and temporal disconnects and the invisibility of regulating services associated with natural hazards is another research challenge that needs to be pursued. As well as the effect of cross-scalar dynamics and its influence on vulnerability, resilience and adaptive capacity.

6.4 References

Abdallah, S., and G. Burham, editors. 2000. *Public health guide for emergencies*. 1st Editio. Boston: The Johns Hopkins School of Hygiene and Public Health and The International Federation of Red Cross and Red Crescent Societies.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change* 16(1):268–281.

Adger, W. N., T. P. Hughes, C. Folke, S. R. Carpenter, and J. Rockström. 2005. Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–9.

Agostinho, A. A., C. C. Bonecker, and L. C. Gomes. 2009. Effects of water quantity on connectivity : the case of the upper Paraná River floodplain. *Echohydrology & Hydrobiology* 9(1):99–113.

Ahammad, R., P. Nandy, and P. Husnain. 2013. Unlocking ecosystem based adaptation opportunities in coastal Bangladesh. *Journal of Coastal Conservation* 17:833–840.

Ainuddin, S., and J. K. Routray. 2012. Earthquake hazards and community resilience in Baluchistan. *Natural Hazards* 63(2):909–937.

Allanson, B. R. 2000. The Knysna Basin Project reviewed - research findings and implications for management for management. *Transactions of the Royal Society of South Africa* 55(2):97–100.

Allen, C. R., L. Gunderson, and A. R. Johnson. 2005. The Use of discontinuities and functional groups to assess relative resilience in complex systems. *Ecosystems* 8(8):958–966.

Ambroise, B. 2004. Variable“active” versus“contributing” areas or periods: a necessary distinction. *Hydrological Processes* 18(6):1149–1155.

Andersson, E., T. McPhearson, P. Kremer, E. Gomez-Baggethun, D. Haase, M. Tuvendal, and D. Wurster. 2015. Scale and context dependence of ecosystem service providing units. *Ecosystem Services* 12:157–164.

Andrade Pérez, A., B. Herrera Fernández, and R. Cazzolla Gatti. 2010. *Building resilience to climate change : ecosystem-based adaptation and lessons from the field. Ecosystem Management Series no. 9* .

Armah, F. A., D. O. Yawson, G. T. Yengoh, J. O. Odoi, and E. K. A. Afrifa. 2010. Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. *Water* 2(2):120–139.

Armitage, D., C. Bene, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social- ecological perspective. *Ecology and Society* 17(4).

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources* 29(1):261–299.

Baard, J. A., and T. Kraaij. 2014. Alien flora of the Garden Route National Park, South Africa. *South African Journal of Botany* 94:51–63.

Bagstad, K. J., G. W. Johnson, B. Voigt, and F. Villa. 2013. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosystem Services* 4:117–125.

Bagstad, K. J., F. Villa, D. Batker, J. Harrison-Cox, B. Voigt, and G. W. Johnson. 2014. From theoretical to actual ecosystem services : mapping beneficiaries and spatial flows in ecosystem service assessments. *Ecology And Society* 19(2).

Bahauddin, K. M., and M. H. Uddin. 2012. Community based risk assessment and adaptation to climate change in Dharam Wetland under Sunamganj District. *Journal of Environmental Science and Natural Resources* 5(2):161–166.

Balmford, A., and T. Whitten. 2003. Who should pay for tropical conservation, and how could the costs be met? *Oryx* 37(02):238–250.

Band, L. E., T. Hwang, T. C. Hales, J. Vose, and C. Ford. 2012. Ecosystem processes at the watershed scale : Mapping and modeling ecohydrological controls of landslides. *Geomorphology* 137(1):159–167.

Baral, H., R. J. Keenan, J. C. Fox, N. E. Stork, and S. Kasel. 2013. Spatial assessment of ecosystem goods and services in complex production landscapes: A case study from south-eastern Australia. *Ecological Complexity* 13:35–45.

Barbedo, J., M. Miguez, D. van der Horst, and M. Marins. 2014. Enhancing ecosystem

services for flood mitigation. *Ecology And Society* 19(2).

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2):169–193.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. *Ambio* 43(4):466–79.

Baró, F., D. Haase, E. Gómez-Baggethun, and N. Frantzeskaki. 2015. Mismatches between ecosystem services supply and demand in urban areas : A quantitative assessment in five European cities. *Ecological Indicators* 55:146–158.

Bastian, O., R. U. Syrbe, M. Rosenberg, D. Rahe, and K. Grunewald. 2013. The five pillar EPPS framework for quantifying, mapping and managing ecosystem services. *Ecosystem Services* 4:15–24.

Beckage, B., and C. Ellinwood. 2008. Fire feedbacks with vegetation and alternative stable states. *Complex Systems* 18(1):159–173.

Bellot, J., A. Bonet, J. R. Sanchez, and E. Chirino. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. *Landscape and Urban Planning* 55:41–53.

Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. *Journal of Vegetation Science* 10(1):243–252.

Benjamin, M. A. 2008. Analysing urban flood risk in low-cost settlements of George, Western Cape, South Africa: Investigating physical and social dimensions. University of Cape Town.

Bennett, E. M., W. Cramer, A. Begossi, G. Cundill, S. Díaz, B. N. Egoh, I. R. Geijzendorffer, C. B. Krug, S. Lavorel, E. Lazos, L. Lebel, B. Martín-López, P. Meyfroidt, H. a Mooney, J. L. Nel, U. Pascual, K. Payet, N. P. Harguindeguy, G. D. Peterson, A.-H. Prieur-Richard, B. Reyers, P. Roebeling, R. Seppelt, M. Solan, P. Tschakert, T. Tscharntke, B. Turner, P. H. Verburg, E. F. Viglizzo, P. C. White, and G. Woodward. 2015a. Linking biodiversity, ecosystem services, and human well-being: three

challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14:76–85.

Bennett, E. M., G. S. Cumming, and G. D. Peterson. 2005. A systems model approach to determining resilience surrogates for case studies. *Ecosystems* 8(8):945–957.

Bennett, N. J., J. Blythe, S. Tyler, N. C. Ban, and N. J. Bennett. 2015b. Communities and change in the anthropocene : understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change*(August):1–20.

Van den Berg, E. C., C. Plarre, H. M. Van den Berg, and M. W. Thompson. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR). Pretoria.

Beven, K., L. Heathwaite, P. Haygarth, D. Walling, R. Brazier, and P. Withers. 2005. On the concept of delivery of sediment and nutrients to stream channels. *Hydrological Processes* 19(2):551–556.

Beven, K. J. J., and M. J. Kirkby. 1979. A physically based , variable contributing area model of basin hydrology. *Hydrological Sciences* 24(1):43–68.

BGIS. 2014. Biodiversity GIS. http://www.bgis.sanbi.org.

Biggs, R., M. Schlüter, D. Biggs, E. L. Bohensky, S. BurnSilver, G. Cundill, V. Dakos, T. M. Daw, L. S. Evans, K. Kotschy, A. M. Leitch, C. Meek, A. Quinlan, C. Raudsepp-Hearne, M. D. Robards, M. L. Schoon, L. Schultz, and P. C. West. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37(1):421–448.

Biscarini, C., S. Di Francesco, F. Nardi, and P. Manciola. 2013. Detailed simulation of complex hydraulic problems with macroscopic and mesoscopic mathematical methods. *Mathematical Problems in Engineering* 2013.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. *Ecological Economics* 29(2):293–301.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology and Evolution* 28(4):230–238.

Boyd, I. ., P. . Freer-Smith, G. C. A, and G. H.C.J. 2014. The consequence of tree pests and diseases for ecosystem services. *Science* 342(2013).

Bozelli, R. L., A. Caliman, R. D. Guariento, L. S. Carneiro, J. M. Santangelo, M. P. Figueiredo-Barros, J. J. F. Leal, A. M. Rocha, L. B. Quesado, P. M. Lopes, V. F. Farjalla, C. C. Marinho, F. Roland, and F. A. Esteves. 2009. Interactive effects of environmental variability and human impacts on the long-term dynamics of an Amazonian floodplain lake and a South Atlantic coastal lagoon. *Limnologica* 39(4):306–313.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32(1):6.1–6.32.

ten Brinke, W. B. M., G. E. M. Saeijs, I. Helsloot, and J. van Alphen. 2008. Safety chain approach in flood risk management. *Proceedings of the ICE - Municipal Engineer* 161(2):93–102.

Brocca, L., F. Melone, and T. Moramarco. 2008. Soil moisture monitoring at different scales for rainfall-runoff modelling. Pages 407–414 *International Congress on Environmental Modelling and Software*.

Brody, S. D., J. E. Kang, and S. Bernhardt. 2009. Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Natural Hazards* 52(1):167–184.

Bronstert, A., D. Niehoff, and G. Burger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities. *Hydrological Processes* 16(2):509–529.

Brown, J. D., and S. L. Damery. 2002. Managing flood risk in the UK : towards an integration of social and technical perspectives. *Royal Geographical Society* 27(1):412–426.

Brown, K., and E. Westaway. 2011. Agency , capacity , and resilience to environmental change : lessons from human and disasters. *The Annual Review of Environment and Resources* 36:321–342.

Burke, I. C., T. G. F. Kittel, W. K. Lauenroth, P. Snook, C. M. Yonker, and W. J. Parton. 1991. Regional analysis of the Great Central Plains. *BioScience* 41(10):685–692.

Carollo, C., R. J. Allee, and D. W. Yoskowitz. 2013. Linking the Coastal and Marine Ecological Classification Standard (CMECS) to ecosystem services : an application to the US Gulf of Mexico. *International Journal of Biodiversity Science, Ecosystem Services & Management* 9:3(March 2015):37–41.

Carpenter, S., K. Arrow, S. Barrett, R. Biggs, W. Brock, A.-S. Crépin, G. Engström, C. Folke, T. Hughes, N. Kautsky, C.-Z. Li, G. McCarney, K. Meng, K.-G. Mäler, S. Polasky, M. Scheffer, J. Shogren, T. Sterner, J. Vincent, B. Walker, A. Xepapadeas, and A. Zeeuw. 2012. General resilience to cope with extreme events. *Sustainability* 4(12):3248–3259.

Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006a. Scenarios for ecosystem services: An overview. *Ecology and Society* 11(1).

Carpenter, S. R., R. Defries, T. Dietz, H. A. Mooney, S. Polasky, W. V Reid, and R. J. Scholes. 2006b. Millennium Ecosystem Assessment: Research Needs. *Science* 314:257–314.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conservation Biology* 21(4):1092–1104.

Casado-Arzuaga, I., I. Madariaga, and M. Onaindia. 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. *Journal of environmental management* 129:33–43.

Castro, A. J., P. H. Verburg, B. Martín-López, M. Garcia-Llorente, J. Cabello, C. C. Vaughn, and E. López. 2014. Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* 132:102–110.

Cattell, R. B. 1983. The scree test for the number of factors. *Multivariate behavioral Research* 1:245–276.

Chakraborty, J., G. a. Tobin, and B. E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Natural Hazards Review* 6(1):23–33.

Chapin, F. S., S. R. Carpenter, G. P. Kofinas, C. Folke, N. Abel, W. C. Clark, P. Olsson, D. M. S. Smith, B. Walker, O. R. Young, F. Berkes, R. Biggs, J. M. Grove, R. L. Naylor, E. Pinkerton, W. Steffen, and F. J. Swanson. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in ecology & evolution* 25(4):241–9.

de Chazal, J., and M. D. A. Rounsevell. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19(2):306–315.

Chief Directorate Surveys and Mapping. 2002. *Chief Directorate: Surveys and Mapping*. Mobray.

Chillo, V., M. Anand, and R. A. Ojeda. 2011. Assessing the use of functional diversity as a measure of ecological resilience in arid rangelands. *Ecosystems* 14(7):1168–1177.

Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12(12):2316–2322.

Cote, M., and A. J. Nightingale. 2012. Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4):475–489.

Cowling, R. M., B. Egoh, A. T. Knight, P. J. O’Farrell, B. Reyers, M. Rouget, D. J. Roux, A. Welz, and A. Wilhelm-Rechman. 2008. An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105(28):9483–9488.

Craig, R. K., and J. B. Ruhl. 2010. Governing for sustainable coasts: Complexity, climate change, and coastal ecosystem protection. *Sustainability* 2(5):1361–1388.

Croke, J., K. Fryirs, and C. Thompson. 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. *Earth Surface Processes and Landforms* 38(12):1444–1456.

Crossman, N. D., B. A. Bryan, and D. M. Summers. 2009. Hotspots of threat and opportunity from widespread reforestation for carbon offsets. Pages 2185–2191 *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*.

Cruz, A., J. Benedicto, and A. Gil. 2011. Socio-economic benefits of natura 2000 in Azores Islands - A case study approach on ecosystem services provided by a special protected area. Pages 1955–1959 *Journal of Coastal Research*.

Cumming, G. S., G. Barnes, S. Perz, M. Schmink, K. E. Sieving, J. Southworth, M. Binford, R. D. Holt, C. Stickler, and T. Holt. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems* 8(8):975–987.

Cumming, G. S., P. Olsson, F. S. Chapin, and C. S. Holling. 2012. Resilience, experimentation, and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28(6):1139–1150.

Curran-Cournane, F., M. Vaughan, A. Memon, and C. Fredrickson. 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland’s valuable soil resources. *Land Use Policy* 39:146–154.

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

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4):598–606.

Cutter, S. L., C. G. Burton, and C. T. Emrich. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal Of Homeland Security And Emergency Management* 7(1).

Dai, L., D. Vorselen, K. S. Korolev, and J. Gore. 2012. Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science (New York, N.Y.)* 336(6085):1175–7.

Darboux, F., C. Gascuel-Odoux, and P. Davy. 2002. Effects of surface water storage by soil

roughness on overland-flow generation. *Earth Surface Processes and Landforms* 27(3):223–233.

Davidson, J. L., I. E. Van Putten, P. Leith, M. Nursey-Bray, E. M. Madin, and J. Neil. 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. *Ecology And Society* 18(3):4.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38(04):370–379.

Death, R. G., I. C. Fuller, and M. G. Macklin. 2015. Resetting the river template: the potential for climate-related extreme floods to transform river geomorphology and ecology. *Freshwater Biology* 60(12):2477–2496.

Depietri, Y., F. G. Renaud, and G. Kallis. 2012. Heat waves and floods in urban areas : a policy-oriented review of ecosystem services. *Sustainability Science* 7(1):95–107.

Dijkshoorn, J. A. 2003. *SOTER database for Southern Africa (SOTERSAF): Technical Report*. International Soil Reference and Information Centre (ISRIC), Wageningen.

Dollar, E. S. J., C. S. James, K. H. Rogers, and M. C. Thoms. 2007. A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* 89(1-2 SPEC. ISS.):147–162.

Downs, P. ., and G. Prienstnall. 2003. Modelling catchment processes. Pages 205–230 *in* G. M. Kondolf and H. Piegay, editors. *Tools in Fluvial Geomorphology*. Wiley; West Sussex.

Du, J., L. Qian, H. Rui, T. Zuo, D. Zheng, Y. Xu, and C.-Y. Xu. 2012. Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *Journal of Hydrology* 464-465:127–139.

Eden District Municipality. 2008. *State of the Environment Report*. George.

Eden District Municipality. 2009. *Eden District Municipality spatial development framework review*. Eden.

Eden District Municipality. 2012. *Eden District Municipality Integrated Development Plan (IDP)*. George.

Egoh, B. N., P. J. O'Farrell, A. Charef, L. Josephine Gurney, T. Koellner, H. Nibam Abi, M. Egoh, and L. Willemen. 2012. An African account of ecosystem service provision: Use, threats and policy options for sustainable livelihoods. *Ecosystem Services* 2:71–81.

Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le, and A. S. Van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127:135–140.

Environmental Systems Research Institute. 2015. *ArcGIS Desktop (ArcInfo) Software*. Redlands, California, USA.

Euwals, R., M. Knoef, and D. van Vuuren. 2010. The trend in female labour force participation: what can be expected for the future? *Empirical Economics* 40(3):729–753.

Evans, C. D., A. Bonn, J. Holden, M. S. Reed, M. G. Evans, F. Worrall, J. Couwenberg, and M. Parnell. 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. *Ecosystem Services* 9:5–19.

Everard, M., B. Pontin, T. Appleby, C. Staddon, E. T. Hayes, J. H. Barnes, and J. W. S. Longhurst. 2013. Air as a common good. *Environmental Science and Policy* 33:354–368.

Fabinyi, M., L. Evans, and S. J. Foale. 2014. Social-ecological systems , social diversity , and power : insights from anthropology and political ecology. *Ecology and Society* 19(4).

Faling, W., J. Tempelhoff, and D. Van. 2012. Rhetoric or action : Are South African municipalities planning for climate change? *Development Southern Africa* 29(2):241–257.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–2068.

Feehan, J., M. Harley, and J. Van Minnen. 2009. Climate change in Europe . 1 . Impact on terrestrial ecosystems and biodiversity . A review*. *Agronomy for Sustainable Development* 29(2009):409–421.

Felipe-Lucia, M. R., F. A. Comín, and E. M. Bennett. 2014. Interactions Among Ecosystem Services Across Land Uses in a Floodplain Agroecosystem. *Ecology And Society* 19(1).

Ferreira, S. 2007. Role of tourism and place identity in the development of small towns in the Western Cape, South Africa. *Urban Forum* 18(3):191–209.

Fischer, J., T. A. Gardner, E. M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, R. Hill, T. P. Hughes, T. Luthe, M. Maass, M. Meacham, A. V Norstrom, G. Peterson, C. Queiroz, R. Seppelt, M. Spierenburg, and J. Tenhunen. 2015. Advancing sustainability through mainstreaming a social – ecological systems perspective. *Currrent Opinion in Environmental Sustainability* 14(JUNE):144–149.

Fischer, J., J. Stott, A. Zerger, G. Warren, K. Sherren, and R. I. Forrester. 2009. Reversing a tree regeneration crisis in an endangered ecoregion. *Proceedings of the National Academy of Sciences of the United States of America* 106(25):10386–10391.

Fitzjohn, C., J. . Ternan, and a. . Williams. 1998. Soil moisture variability in a semi-arid gully catchment: implications for runoff and erosion control. *Catena* 32(1):55–70.

Flanagan, B. E., E. W. Gregory, E. J. Hallisey, J. L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1).

Foley, J. A., G. P. Asner, M. H. Costa, M. T. Coe, R. Defries, H. K. Gibbs, E. A. Howard, S. Olson, J. Patz, N. Ramankutty, and P. Snyder. 2007. Amazonia revealed : forest degradaton and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5(1):25–32.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16(3):253–267.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31(5):437–40.

Frazier, T. G., C. M. Thompson, R. J. Dezzani, and D. Butsick. 2013. Spatial and temporal quantification of resilience at the community scale. *Applied Geography* 42:95–107.

Garcia-Llorente, M., I. Iniesta-Arandia, B. A. Willaarts, P. A. Harrison, P. Berry, M. del M.

Bayo, A. J. Castro, C. Montes, B. Martín-López, and A. J. Castro. 2015. Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds Biophysical and sociocultural factors underlying spatial trade-offs of ecosystem services in semiarid watersheds. *Ecology and Society* 20(3):39.

Garen, D. C., and D. S. Moore. 2005. “Curve number hydrology in water quality modeling: Uses, abuses, and future directions,” - Reply to discussion. *Journal of the American Water Resources Association* 41(6):1493–1494.

German, L., G. Villamor, E. Twine, J. Sandra, and B. Kidane. 2010. Environmental Services and the Precautionary Principle : Using Scenarios to Reconcile Conservation and Livelihood Objectives in Upper Catchments. *Journal of Sustainable Forestry*(March 2015):37–41.

Ghaley, B. B., L. Vesterdal, and J. R. Porter. 2014. Quantification and valuation of ecosystem services in diverse production systems for informed decision-making. *Environmental Science and Policy* 39:139–149.

Godschalk, D. R. 2002. Urban hazard mitigation : Creating resilient cities. *Natural Hazards Review* 4(3):136–143.

Goldman, R. L., B. H. Thompson, and G. C. Daily. 2007. Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services. *Ecological Economics* 64(2):333–343.

Gómez-Limón, J. A., and L. Riesgo. 2008. Alternative approaches on constructing a composite indicator to measure agricultural sustainability. Pages 1–25 *107th EAAE Seminar "Modelling of Agricultural and Rural Develpment Policies*. Sevilla, Spain.

Gordon, L. J., C. M. Finlayson, and M. Falkenmark. 2010. Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* 97:512–519.

Grimaldi, S., a. Petroselli, and N. Romano. 2013. Green-Ampt Curve-Number mixed procedure as an empirical tool for rainfall-runoff modelling in small and ungauged basins. *Hydrological Processes* 27(8):1253–1264.

de Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in

integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7(3):260–272.

De Groot, R. S., M. A. Wilson, and R. M. J. Boumans. 2002. A typology for the classiciation, description and valuation of ecosytem functions, goods and services. *Ecological Economics* 41(May):1–20.

Guerry, A. D., S. Polasky, J. Lubchenco, R. Chaplin-Kramer, G. C. Daily, R. Griffin, M. Ruckelshaus, I. J. Bateman, A. Duraiappah, T. Elmqvist, M. W. Feldman, C. Folke, J. Hoekstra, P. M. Kareiva, B. L. Keeler, S. Li, E. McKenzie, Z. Ouyang, B. Reyers, T. H. Ricketts, J. Rockström, H. Tallis, and B. Vira. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences* 112(24):201503751.

Gunderson, L. 2010. Ecological and human community resilience in response to natural disasters. *Ecology And Society* 15(2):18.

Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. *Ecological Economics* 38(1):141–154.

Guo, Z., L. Zhang, and Y. Li. 2010. Increased dependence of humans on ecosystem services and biodiversity. *PloS one* 5(10).

Hahn, C., V. Prasuhn, C. Stamm, D. G. Milledge, and R. Schulin. 2014. A comparison of three simple approaches to identify critical areas for runoff and dissolved reactive phosphorus losses. *Hydrology and Earth System Sciences* 18(8):2975–2991.

Hahn, M. B., A. M. Riederer, and S. O. Foster. 2009. The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change* 19(1):74–88.

Hannon, B., and M. Ruth. 2001. *Dynamic Modeling*. *Dynamic modeling*. Springer Science and Business Media.

Hao, F., X. Lai, and W. Ouyang. 2012. Effects of land use changes on the ecosystem service values of a reclamation farm in Northeast China. *Environmental Management*.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D.

Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296(5576):2158–2162.

Hassel, H. 2012. Risk and vulnerability analysis in practice: evaluation of analyses conducted in Swedish municipalities. *Natural Hazards* 63(2):605–628.

Häyhä, T., and P. P. Franzese. 2014. Ecosystem services assessment: A review under an ecological-economic and systems perspective. *Ecological Modelling* 289:124–132.

Hein, L., K. van Koppen, R. S. de Groot, and E. C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57(2):209–228.

Hinkel, J. 2011. "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science-policy interface. *Global Environmental Change* 21(1):198–208.

Hough, R. L. 2014. Biodiversity and human health : evidence for causality ? *Biodiversity Conservation* 23:267–288.

Howe, C., H. Suich, P. van Gardingen, A. Rahman, and G. M. Mace. 2013. Elucidating the pathways between climate change, ecosystem services and poverty alleviation. *Current Opinion in Environmental Sustainability* 5(1):102–107.

Hümann, M., G. Schüler, C. Müller, R. Schneider, M. Johst, and T. Caspari. 2011. Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology* 409(3-4):637–649.

Humby, T. 2012. *Analysis of legislation related to disaster risk reduction in South Africa*. International Federation of Red Cross and Red Crescent Societies, Geneva, Switzerland.

IBM Corp. 2012, March 24. IBM SPSS Statistics for Windows, Version 21.0. IBM Corp, Armonk, New York.

Ingraham, M. W., and S. Gilliland. 2008. The value of ecosystem services provided by the U.S National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 7:608–618.

IPCC. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. (C. B. Field, V. Barros, T. F. Stocker, and Q. Dahe, editors).

Cambridge University Press, Cambridge.

Iverson, L., C. Echeverria, L. Nahuelhual, and S. Luque. 2014. Ecosystem services in changing landscapes: An introduction. *Landscape Ecology* 29(2):181–186.

Jentsch, A., J. Kreyling, M. Elmer, E. Gellesch, B. Glaser, K. Grant, R. Hein, M. Lara, H. Mirzae, S. E. Nadler, L. Nagy, D. Otieno, K. Pritsch, U. Rascher, M. Schädler, M. Schloter, B. K. Singh, J. Stadler, J. Walter, C. Wellstein, J. Wöllecke, and C. Beierkuhnlein. 2011. Climate extremes initiate ecosystem-regulating functions while maintaining productivity. *Journal of Ecology* 99(3):689–702.

Jones, L., L. Norton, Z. Austin, A. L. Browne, D. Donovan, B. A. Emmett, Z. J. Grabowski, D. C. Howard, J. P. G. Jones, J. O. Kenter, W. Manley, C. Morris, D. A. Robinson, C. Short, G. M. Siriwardena, C. J. Stevens, J. Storkey, R. D. Waters, and G. F. Willis. 2016. Stocks and flows of natural and human-derived capital in ecosystem services. *Land Use Policy* 52:151–162.

Kakuru, W., N. Turyahabwe, and J. Mugisha. 2013. Total Economic Value of Wetlands Products and Services in Uganda. *The Scientific World Journal* 2013.

Karp, D. S., H. V. Moeller, and L. O. Frishkoff. 2013. Nonrandom extinction patterns can modulate pest control service decline. *Ecological Applications* 23(4):840–849.

Kaźmierczak, A., and G. Cavan. 2011. Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and Urban Planning* 103(2):185–197.

Keeler, B. L., S. Polasky, K. a. Brauman, K. a. Johnson, J. C. Finlay, a. O'Neill, K. Kovacs, and B. Dalzell. 2012. Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* 109(45).

Khan, S., L. Yufeng, and A. Ahmad. 2009. Analysing complex behaviour of hydrological systems through a system dynamics approach. *Environmental Modelling & Software* 24(12):1363–1372.

Kienast, F., J. Bolliger, M. Potschin, R. S. de Groot, P. H. Verburg, I. Heller, D. Wascher, and R. Haines-Young. 2009. Assessing landscape functions with broad-scale

environmental data: insights gained from a prototype development for Europe. *Environmental management* 44(6):1099–120.

Kim, J., A. Warnock, V. Y. Ivanov, and N. D. Katopodes. 2012. Coupled modeling of hydrologic and hydrodynamic processes including overland and channel flow. *Advances in Water Resources* 37:104–126.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist, and B. H. Walter. 2006. Resilience and regime shifts: assesing cascading effects. *Ecology and Society* 11(1):20.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, E. Pawelzik, and T. Tscharntke. 2013. Bee pollination improves crop quality , shelf life and commercial value. *Proceedings of the Royal Society B* 281.

Koschke, L., C. Lorz, C. Fürst, T. Lehmann, and F. Makeschin. 2014. Assessing hydrological and provisioning ecosystem services in a case study in Western Central Brazil. *Ecological Processes* 3(1):2.

Kotzee, I., and B. Reyers. 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators* 60:45–53.

Kremen, C., and R. S. Ostfeld. 2005. Call to ecologists : measuring , analyzing , managing ecosystem services. *Ecological Society of America* 3(10):540–548.

Krishna, A., and E. Shrader. 1999. Social captial assessment tool. *Conference on Social Capital and Poverty Reduction*. Washington.

Krishnan, V. 2010. Constructing an area-based socioeconomic index: A principal components analysis approach. *Early Child Develoment Mapping Project Alberta*.

Kumar, P., M. Kumar, and L. Garrett. 2014. Behavioural foundation of response policies for ecosystem management: What can we learn from Payments for Ecosystem Services (PES). *Ecosystem Services* 10:128–136.

Kumar, P., M. Verma, M. D. Wood, and D. Negandhi. 2010. *Guidance manual for the valuation of regulating services*. Nairobi-Kenya.

Kumar, P., and M. D. Wood. 2010. *Valuation of regulating services of ecosystems: methodology and applications*. Routledge.

Lamargue, P., U. Tappeiner, C. Turner, M. Steinbacher, R. D. Bardgett, U. Szukics, M. Schermer, and S. Lavorel. 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. *Regional Environmental Change* 11:791–804.

Lane, S. N., C. J. Brookes, R. J. Hardy, J. Holden, T. D. James, M. J. Kirkby, A. T. Mcdonald, V. Tayefi, and D. Yu. 2003. Land management, flooding and environmental risk: New approaches to a very old question. *CIWEM National Conference*.

Lane, S. N., C. J. Brookes, A. Louise Heathwaite, and S. M. Reaney. 2006. Surveillant Science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics* 57(2):239–257.

Lane, S. N., S. M. Reaney, and A. L. Heathwaite. 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. *Water Resources Research* 45(8):0–10.

Lant, C. L., J. B. Ruhl, and S. E. Kraft. 2008. The Tragedy of Ecosystem Services. *BioScience* 58(10):969.

Laterra, P., P. Barral, A. Carmona, and L. Nahuelhual. 2016. Focusing Conservation Efforts on Ecosystem Service Supply May Increase Vulnerability of Socio-Ecological Systems. *Plos One* 11(5):e0155019.

Laterra, P., M. E. Orúe, and G. C. Booman. 2012. Spatial complexity and ecosystem services in rural landscapes. *Agriculture, Ecosystems and Environment* 154:56–67.

Laura, M. I., A. A. Keri, and T. Rusu. 2011. Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Techniques , in Roşia Poieni Mining Area (Romania). *ProEnvironment* 4:240–246.

Layke, C. 2009. Measuring nature’s benefits : A preliminary roadmap for improving ecosystem service indicators. *World Resource Institute*:36pp.

Leconte, R., C. Marche, and J. Rousselle. 2003. Historical evolution of flooding damage on a USA/Quebec river basin. *Journal Of The American Water Resources Association* 7:1385–1396.

Lesschen, J. P., J. M. Schoorl, and L. H. Cammeraat. 2009. Modelling runoff and erosion for

a semi-arid catchment using a multi-scale approach based on hydrological connectivity. *Geomorphology* 109(3-4):174–183.

Levin, S., T. Xepapadeas, A.-S. Crépin, J. Norberg, A. de Zeeuw, C. Folke, T. Hughes, K. Arrow, S. Barrett, G. Daily, P. Ehrlich, N. Kautsky, K.-G. Mäler, S. Polasky, M. Troell, J. R. Vincent, and B. Walker. 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environment and Development Economics* 18(02):111–132.

Lewis, J. E. 1989. Climatic Change and its Effects on Water Resources for Canada: A Review. *Canadian Water Resources Journal* 14(1):34–55.

Lin, Z., C. Yun, G. Huili, J. Weiguo, Z. Wenji, and X. Yanfang. 2011. Economic value evaluation of wetland service in Yeyahu Wetland Nature Reserve , Beijing. *Chinese Geographical Science* 21(40771170):744–752.

Lindemann-Matthies, P., D. Keller, X. Li, and B. Schmid. 2014. Attitudes toward forest diversity and forest ecosystem services — a cross-cultural comparison between China and Switzerland. *Journal of Plant Ecology* 7(1):1–9.

Liquete, C., G. Zulian, I. Delgado, A. Stips, and J. Maes. 2013. Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators* 30:205–217.

Liu, J., T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor. 2007. Complexity of Coupled Human and Natural Systems. *Science* 317(5844):1513–1516.

Locatelli, B., and R. Vignola. 2009. Managing watershed services of tropical forests and plantations : Can meta-analyses help ? *Forest Ecology and Management* 258(9):1864–1870.

Logsdon, R. A., and I. Chaubey. 2013. A quantitative approach to evaluating ecosystem services. *Ecological Modelling* 257:57–65.

Lorenz, D. F. 2010. The diversity of resilience: contributions from a social science perspective. *Natural Hazards* 67(1):7–24.

Lundy, L., and R. Wade. 2011. Integrating sciences to sustain urban ecosystem services.

Progress in Physical Geography 35:653–669.

MA. 2003. *Ecosystems and Human Well-being: A Framework for Assessment*. (J. Alcamo and E. M. Bennett, editors). Island Press, Washington.

MA. 2005. *Ecosystems and human well-being*. Washington.

Macgregor, H. 2005. *Disaster debriefing December 2004 cut off low: Overberg , Cape Winelands Central Karoo and Eden District Municipalities: Commissioned by the department of provincial local goverment and housing*.

Maclean, K., M. Cuthill, and H. Ross. 2014. Six attributes of social resilience. *Journal of Environmental Planning and Management* 57(1):144–156.

Maes, J., M. L. Paracchini, G. Zulian, M. B. Dunbar, and R. Alkemade. 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* 155:1–12.

Magis, K. 2010. Community resilience: An indicator of social sustainability. *Society & Natural Resources* 23(5):401–416.

Le Maitre, D. C., P. J. O. Farrell, and B. Reyers. 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientist in the development of sustainability science? *South African Journal Of Science*(October):367–376.

Le Maitre, D. C., I. M. Kotzee, and P. J. O. Farrell. 2014. Land Use Policy Impacts of land-cover change on the water flow regulation ecosystem service : Invasive alien plants , fire and their policy implications. *Land Use Policy* 36:171–181.

Malone, E. L., and A. L. Brenkert. 2008. Uncertainty in resilience to climate change in India and Indian states. *Climatic Change* 91(3-4):451–476.

Maree, B. 2010. Structure and status of the intertidal wetlands of the Knysna Estuary. *Transactions Of The Royal Society Of South Africa*(December 2011):37–41.

Marker, M. E. 2003. The Knysna Basin, South Africa: geomorphology, landscape sensitivity and sustainability. *The Geographical Journal* 169(1):32–42.

Marker, M. E., and P. J. Holmes. 2005. Landscape evolution and landscape sensitivity : the

case of the southern Cape. *South African Journal of Science* 101:53–60.

Marshall, N. A., and P. A. Marshall. 2007. Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Soceity* 12(1):1(1).

Martínez-Harms, M. J., and P. Balvanera. 2012. Methods for mapping ecosystem service supply : a review. *International Journal of Biodiversiity Science, Ecosystem Services and Management* 8(March 2015):37–41.

Martin-Lopez, B., I. Iniesta-Arandia, M. Garcia-Llorente, I. Palomo, I. Casado-Arzuaga, D. Garcia Del Amo, E. Gomez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. Gonzalez, F. Santos-Martín, M. Onaindia, C. Lopez-Santiago, C. Montes, B. Martín-López, I. Iniesta-Arandia, M. García-Llorente, I. Palomo, I. Casado-Arzuaga, D. G. Del Amo, E. Gómez-Baggethun, E. Oteros-Rozas, I. Palacios-Agundez, B. Willaarts, J. A. González, F. Santos-Martín, M. Onaindia, C. López-Santiago, and C. Montes. 2012. Uncovering ecosystem service bundles through social preferences. *PLOS one* 7(6):e38970.

Matthews, R. B., M. van Noordwijk, E. Lambin, P. Meyfroidt, J. Gupta, L. Verchot, K. Hergoualc'h, and E. Veldkamp. 2014. Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change* 19(6):907–925.

Mayunga, J. S. 2007. Understanding and applying the concept of community disaster resilience : A capital-based approach. *Working paper for the summer academy for social vulnerability and resilience building 22-29 July 2007, Munich.*:22–28.

McDonnell, J. J., M. Sivapalan, K. Vaché, G. Grant, R. Haggerty, C. Hinz, R. Hooper, J. Kirchner, M. L. Roderick, J. Selker, and M. Weiler. 2007. Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology. *Water Resources Research* 43(7):W07301.

Meehan, T. D., C. Gratton, E. Diehl, N. D. Hunt, D. F. Mooney, S. J. Ventura, B. L. Barham, and R. D. Jackson. 2013. Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*

8(11):e80093.

Mélice, J., and C. J. C. Reason. 2007. Return period of extreme rainfall at George , South Africa. *South African Journal of Science* 103(December):499–501.

Merz, B., A. H. Thieken, and M. Gocht. 2007. Flood risk mapping at the local scale: concepts and challenges. Pages 231–251 *in* S. Begum, M. Stive, and J. W. Hall, editors. *Flood Risk Management in Europe: Innovation in policy and practice*. Springer.

Miao, X., D. Banister, and Y. Tang. 2013. Embedding resilience in emergency resource management to cope with natural hazards. *Natural Hazards* 69(3):1389–1404.

Milledge, D. G., S. N. Lane, A. L. Heathwaite, and S. M. Reaney. 2012. A Monte Carlo approach to the inverse problem of diffuse pollution risk in agricultural catchments. *The Science of the Total Environment* 433:434–49.

Mirza, M. M. Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy* 3(3):233–248.

Mitchell, J. 1989. The “greenhouse” effect and climate change. *Reviews of Geophysics*(89):115–139.

Mohammad, F. S., and J. Adamowski. 2015. Interfacing the geographic information system, remote sensing, and the soil conservation service–curve number method to estimate curve number and runoff volume in the Asir region of Saudi Arabia. *Arabian Journal of Geosciences* 8(12):11093–11105.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Physical therapy* 89(9):873–880.

Mooney, H., A. Larigauderie, M. Cesario, T. Elmquist, O. Hoegh-Guldberg, S. Lavorel, G. M. Mace, M. Palmer, R. Scholes, and T. Yahara. 2009. Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability* 1(1):46–54.

Moore, I. D., R. B. Grayson, and A. R. Ladson. 1991. Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes* 5(1):3–30.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 23(1):1–18.

Morrow, B. H. 2008. *Community resilience: A social justice perspective*. Miami, Florida.

Mouchet, M. a., P. Lamarque, B. Martín-López, E. Crouzat, P. Gos, C. Byczek, and S. Lavorel. 2014. An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* 28:298–308.

Munang, R., I. Thiaw, K. Alverson, J. Liu, and Z. Han. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability* 5(1):47–52.

Murphy, B. L. 2007. Locating social capital in resilient community-level emergency management. *Natural Hazards* 41(2):297–315.

Næss, L. O., G. Bang, S. Eriksen, and J. Vevatne. 2005. Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* 15(2):125–138.

Nardo, M., M. Saisana, A. Saltelli, and S. Tarantola. 2005. *Tools for composite indicators building*. Ispra, Italy.

Nedkov, S., and B. Burkhard. 2012. Flood regulating ecosystem services—Mapping supply and demand, in the Etropole municipality, Bulgaria. *Ecological Indicators* 21:67–79.

Nel, J. L., D. C. Le Maitre, D. C. Nel, B. Reyers, S. Archibald, B. W. van Wilgen, G. G. Forsyth, A. K. Theron, P. J. O’Farrell, J.-M. M. Kahinda, F. A. Engelbrecht, E. Kapangaziwiri, L. van Niekerk, and L. Barwell. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *PloS one* 9(5):e95942.

Nelson, G. C. 2005. Drivers of ecosystem change: summary chapter. Pages 73–76 *Ecosystems and Human Well-being: Current State and Trends*.

Nelson, G. C., E. Bennett, A. A. Berhe, K. Cassman, R. Defries, T. Dietz, A. Dobermann, A. Dobson, A. Janetos, M. Levy, D. Marco, N. Nebojsa, B. O’Neill, R. B. Norgaard, G. Petschel-Held, D. Ojima, P. Pingali, R. Watson, and M. Zurek. 2006. Anthropogenic drivers of ecosystem change : an overview. *Ecology And Society* 11(11):29.

Nelson, K. S., M. D. Abkowitz, and J. V. Camp. 2015. A method for creating high resolution maps of social vulnerability in the context of environmental hazards. *Applied Geography* 63:89–100.

van Nes, E. H., and M. Scheffer. 2007. Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift. *The American naturalist* 169(6):738–47.

Nieber, J. L., and R. C. Sidle. 2010. How do disconnected macropores in sloping soils facilitate preferential flow? *Hydrological Processes* 24(12):1582–1594.

van Niekerk, D., J. Tempelhoff, W. Faling, L. Thompson, D. Jordaan, C. Coetsee, and Y. Maartens. 2009. *The effects of climate change in two flood laden and drought stricken areas in South Africa: Responses to climate change - past, present and future.* Potchefstroom, South Africa.

Norris, F. H., S. P. Stevens, B. Pfefferbaum, K. F. Wyche, and R. L. Pfefferbaum. 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 41(1-2):127–50.

Nunez, D., L. Nahuelhaul, and C. Oyarzun. 2006. Forests and water : The value of native temperate forests in supplying water for human consumption. *Ecological Economics* 58:606–616.

Nyström, M., N. A. J. Graham, J. Lokrantz, and A. V Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. *Coral Reefs* 27(4):795–809.

O'Connell, E., J. Ewen, G. O'Donnell, and P. Quin. 2007. Is there a link between agricultural land-use management and flooding? *Hydrology and Earth System Sciences* 11(1):96–107.

de Oliveira Mendes, J. M. 2009. Social vulnerability indexes as planning tools: beyond the preparedness paradigm. *Journal of Risk Research* 12(1):43–58.

Olsson, P., C. Folke, and F. Berkes. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental management* 34(1):75–90.

Orencio, P. M., and M. Fujii. 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of*

Disaster Risk Reduction 3:62–75.

Osuri, A. M., V. S. Kumar, and M. Sankaran. 2014. Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management* 329:375–383.

Outeiro, L., and S. Villasante. 2013. Linking salmon aquaculture synergies and trade-offs on ecosystem services to human wellbeing constituents. *Ambio* 42(8):1022–1036.

Palmer, M. A., D. P. Lettenmaier, N. L. Poff, S. L. Postel, B. Richter, and R. Warner. 2009. Climate change and river ecosystems: protection and adaptation options. *Environmental management* 44(6):1053–68.

Palomo, I., B. Martin-Lopez, P. Alcorlo, and M. Carlos. 2014a. Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. *Ecosystems* 17:1202–1215.

Palomo, I., B. Martin-Lopez, P. Zorrilla-Miras, and D. G. Del Amo. 2014b. Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. *Regional Environmental Change* 14:237–251.

Parmesan, C., G. Yohe, and Y. G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918):37.

Partridge, T. ., E. S. . Dollar, J. Moolman, and L. H. Dollar. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* 65(1):1–47.

Pattison, I., and S. N. Lane. 2012. The link between land-use management and fluvial flood risk: A chaotic conception? *Progress in Physical Geography* 36(1):72–92.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438(7066):310–317.

Pauchard, A., M. Aguayo, E. Peña, and R. Urrutia. 2006. Multiple effects of urbanization on the biodiversity of developing countries : the case of fast-growing metropolitan area (Concepción, Chile). *Biological Conservation* 127.3:272–281.

Pauw, J. 2009. *Challenges to sustainability in the Garden Route: Water, Land and Economy*.

Garden. George.

Payet, K., M. Rouget, K. J. Esler, B. Reyers, T. Rebelo, M. W. Thompson, and J. H. J. Vlok. 2013. Effect of land cover and ecosystem mapping on ecosystem-risk assessment in the Little Karoo, South Africa. *Conservation Biology* 27(3):531–634.

Pelling, M., and A. Özerdem. 2002. The macro-economic impact of disasters. *Progress in Development Studies* 2(4):283–305.

Pereira, E., C. Queiroz, H. M. Pereira, and L. Vicente. 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. *Ecology and Society* 10(2).

Perrings, C., A. Duraiappah, A. Larigauderie, and H. Mooney. 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331(6021):1139–1140.

Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honz??k, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecological Complexity* 7(3):378–388.

Petz, K., J. Glenday, and R. Alkemade. 2014. Land management implications for ecosystem services in a South African rangeland. *Ecological Indicators* 45:692–703.

Petz, K., and A. P. E. van Oudehoven. 2012. Modelling land management effect on ecosystem functions and services : a study in the Netherlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8(March 2015):37–41.

Pinto, R., V. N. de Jonge, J. M. Neto, T. Domingos, J. C. Marques, and J. Patrício. 2013. Towards a DPSIR driven integration of ecological value, water uses and ecosystem services for estuarine systems. *Ocean & Coastal Management* 72:64–79.

Pirard, R. 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. *Environmental Science & Policy* 19-20:59–68.

Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering sciences* 360(1796):1497–510.

Posthumus, H., C. Hewett, J. Morris, and P. Quinn. 2008. Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management* 95(7):787–798.

Priddy, K. L., and P. E. Keller. 2005. *Artificial Neural Networks: An introduction*. SPIE Press, Washington, DC.

Prior, T., and J. Hagmann. 2013. Measuring resilience: methodological and political challenges of a trend security concept. *Journal of Risk Research*(January 2015):37–41.

Puigdefábregas, J. 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30(2):133–147.

Quijas, S., L. E. Jackson, M. Maass, B. Schmid, D. Raffaelli, and P. Balvanera. 2012. Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment. *Journal of Applied Ecology* 49(4):929–940.

RADAR. 2010. *RADAR Western Cape risk and development annual review disaster mitigation for sustainable livelihoods programme*. Peri-Peri Publications, University of Cape Town. South Africa.

Radford, K. G., and P. James. 2013. Changes in the value of ecosystem services along a rural – urban gradient : A case study of Greater Manchester , UK. *Landscape and Urban Planning* 109:117–127.

Raju, E., and D. Van Niekerk. 2013. Intra-governmental coordination for sustainable disaster recovery: A case-study of the Eden District Municipality, South Africa. *International Journal of Disaster Risk Reduction* 4:92–99.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107(11):5242–7.

Raymond, C. M., B. A. Bryan, D. Hatton, A. Cast, S. Strathearn, A. Grandgirard, and T. Kalivas. 2008. Mapping community values for natural capital and ecosystem services. *Ecological Economics* 68(5):1301–1315.

Reaney, S. M., S. N. Lane, A. L. Heathwaite, and L. J. Dugdale. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance.

Ecological Modelling 222(4):1016–1029.

Reisi, M., L. Aye, A. Rajabifard, and T. Ngo. 2014. Transport sustainability index: Melbourne case study. *Ecological Indicators* 43:288–296.

Reyers, B., P. J. O. Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem Services , land-cover change , and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecology And Society* 14(1).

Rial, J. A., A. Pielke ST, Roger, M. Beniston, N. De Noblet-Ducoudré, R. Prinn, J. F. Reynolds, and J. D. Salas. 2004. Nonlinearities , feedbacks and critical thresholds within the earth 's climate system. *Climatic change* 65:11–38.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

Rohlf, D. J. 2013. Integrating law, policy, and science in managing and restoring ecosystems. Pages 42–66 *The Laws of Nature: Managing Ecosystems for A Sustainable Future*. The University of Akron Press.

Roura-Pascual, N., D. M. Richardson, R. M. Krug, A. Brown, R. A. Chapman, G. G. Forsyth, D. C. Le Maitre, M. P. Robertson, L. Stafford, B. W. Van Wilgen, A. Wannenburgh, and N. Wessels. 2009. Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation* 142(8):1595–1604.

Russell, I. I. A. 2013. Spatio-temporal variability of surface water quality parameters in a South African estuarine lake system. *African Journal of Aquatic Science* 38(1):53–66.

Saad, R., M. Margni, T. Koellner, B. Wittstock, and L. Deschênes. 2011. Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context. *The International Journal of Life Cycle Assessment* 16(3):198–211.

Saisana, M., and S. Tarantola. 2002. *State-of-the-art report on current methodologies and practices for composite indicator development*. Italy.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-

Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Skykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* 287(March):1770 – 1774.

Salvati, L., and M. Carlucci. 2014. A composite index of sustainable development at the local scale: Italy as a case study. *Ecological Indicators* 43:162–171.

Salzman, J. 2005. The promise and perils of payments for ecosystem services. *International Journal of Innovation and Sustainable Development* 1(1):5–20.

Sanders, C. H., and M. C. Phillipson. 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information* 31(3):210–221.

Santos-Martin, F., B. Martin-Lopez, M. Garcia-Llorent, M. Aguado, J. Benayas, C. Montes, F. Santos-Martín, B. Martín-López, M. García-Llorente, M. Aguado, J. Benayas, and C. Montes. 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PloS one* 8(9):e73249.

Savenije, H. H. G. 2010. Topography driven conceptual modelling (FLEX-Topo). *Hydrology and Earth System Sciences* 14(12):2681–2692.

Scheffer, M., W. Brock, and F. Westley. 2000. Socioeconomic mechanisms preventing optimum use of ecosystem services: An interdisciplinary theoretical analysis. *Ecosystems* 3(5):451–471.

Schelfaut, K., B. Pannemans, I. van der Craats, J. Krywkow, J. Mysiak, and J. Cools. 2011. Bringing flood resilience into practice: the FREEMAN project. *Environmental Science & Policy* 14(7):825–833.

Scheraga, J. D., and A. E. Grambsch. 1998. Risks , opportunities , and adaptation to climate change. *Climate Research* 10:85–95.

Scholes, R. J., and R. Biggs. 2005. A biodiversity intactness index. *Nature* 434(7029):45–49.

Schröter, M., D. N. Barton, R. P. Remme, and L. Hein. 2014. Accounting for capacity and flow of ecosystem services: A conceptual model and a case study for Telemark, Norway. *Ecological Indicators* 36:539–551.

Schüler, G. 2006. Identification of flood-generating forest areas and forestry measures for water retention. *Journal Forest Snow and Landscape Research* 80(1):99–114.

Schulze, R. E. 2008. *South African atlas of climatology and agrohydrology*. Pretoria.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. *Journal of Applied Ecology* 48(3):630–636.

Simonit, S., and C. Perrings. 2011. Sustainability and the value of the "regulating" services: Wetlands and water quality in Lake Victoria. *Ecological Economics* 70(6):1189–1199.

Sitas, N., H. E. Prozesky, K. J. Esler, and B. Reyers. 2013. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 29(8):1315–1331.

Sitas, N., H. Prozesky, K. Esler, and B. Reyers. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6):3802–3824.

Sivapalan, M. 2005. 13 : Pattern , Process and Function : Elements of a Unified Theory of Hydrology at the Catchment. *Encyclopedia of Hydrological Sciences*.

Smit, B., and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3):282–292.

Smith, P., M. R. Ashmore, H. I. J. Black, P. J. Burgess, C. D. Evans, T. A. Quine, A. M. Thomson, K. Hicks, and H. G. Orr. 2013. The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology* 50(4):812–829.

Smithers, J. C., and R. E. Schulze. 2002. *Design rainfall and flood estimation in South Africa*. Pietermaritzburg.

Song, S., B. Schmalz, and N. Fohrer. 2014. Simulation and comparison of stream power in-channel and on the floodplain in a German lowland area. *Journal of Hydrology and Hydromechanics* 62(2):133–144.

South African Local Goverment Association(SALGA). 2013. *Disaster risk reduction : A*

multi-stakeholder approach to targeted intervention in selected municipalities. Pretoria.

Spector, J. M., D. L. Christensen, A. V Sioutine, and D. Mccormack. 2001. Models and simulations for learning in complex domains : using causal loop diagrams for assessment and evaluation. *System Dynamics Review* 17:517–545.

Statistics South Africa. 2011. Statistics South Africa | The South Africa I Know, The Home I Understand. http://beta2.statssa.gov.za/.

Statistics South Africa. 2012. *Census 2011 Municipal report: Western Cape*. Pretoria.

Streck, C., and S. M. Scholz. 2006. The role of forests in global climate change : whence we come and where we go. *International Affairs* 5(July):861–879.

Stürck, J., A. Poortinga, and P. H. Verburg. 2014. Mapping ecosystem services: The supply and demand of flood regulation services in Europe. *Ecological Indicators* 38:198–211.

Sutton, J., L. Palen, and I. Shklovski. 2008. Backchannels on the front lines: Emergent uses of social media in the 2007 southern California wildfires. *Proceedings of the 5th International* ….

Swinton, S. M., F. Lupi, G. P. Robertson, D. A. Landis, F. Lupi, G. P. Robertson, and S. M. Swinton. 2015. Ecosystem services from agriculture: Looking beyond the usual suspects. *American Journal of Agricultural Economics* 88(5):1160–1166.

Syrbe, R.-U., and U. Walz. 2012. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* 21:80–88.

Tallis, H., H. Mooney, S. Andelman, P. Balvanera, and W. Cramer. 2012. A global system for monitoring ecosystem service change. *BioScience* 62(11):977–986.

Tardieu, L., S. Roussel, and J. Salles. 2013. Assessing and mapping global climate regulation service loss induced by terrestrial transport infrastructure construction. *Ecosystem Services* 4:73–81.

TEEB. 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, clonclusions and recommendations of TEEB.*

Tempelhoff, J., I. Gouws, and K. Botha. 2009. The December 2004-January 2005 floods in

the Garden Route region of the Southern Cape, South Africa. *Journal of Disaster Risk Studies* 2(1):93–112.

Terrado, M., V. Acuña, D. Ennaanay, H. Tallis, and S. Sabater. 2014. Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin. *Ecological Indicators* 37(PART A):199–209.

Tetzlaff, D., C. Soulsby, P. J. Bacon, and A. F. Youngson. 2007. Connectivity between landscapes and riverscapes — a unifying theme in integrating hydrology and ecology in catchment science ? *Hydrological Processes* 1389(April):1385–1389.

Thakur, P. K., S. Maiti, N. C. Kingma, V. Hari Prasad, S. P. Aggarwal, and A. Bhardwaj. 2011. Estimation of structural vulnerability for flooding using geospatial tools in the rural area of Orissa, India. *Natural Hazards* 61(2):501–520.

Thomas, A. 2015. Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment / Water Management Area Using GIS. *International Journal of Advanced Remote Sensing and GIS* 4(1):828–862.

Tierney, K., and M. Bruneau. 2007. Conceptualizing and Measuring Resilience: A key to disaster loss reduction. *TR News*.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and society* 9(2):10.

Turner II, B. L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4):570–576.

Turner, M. G., D. C. Donato, and W. H. Romme. 2012. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. *Landscape Ecology* 28(6):1081–1097.

Turpie, J. K., J. B. Adams, A. Joubert, T. D. Harrison, B. M. Colloty, R. C. Maree, and A. K. Whitfield. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation.

UN. 2014. *World urbanisation prospects: The 2014 revision, highlights*. Department of Economic and Social Affairs, Population Division. United Nations.

USDA. 1986. *Urban Hydrology for Small Watersheds*. United States Department of Agricuture, Natural resources Conservation Service, Washington DC.

Uy, N., and R. Shaw. 2013. Ecosystem resilience and community values: Implications to ecosystem-based adaptation. *Journal of Disaster Research* 8(1):201–202.

Vidal-Abarca, M. R., M. L. Suárez-Alonso, F. Santos-Martín, B. Martín-López, J. Benayas, and C. Montes. 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: An ecosystem services approach. *Ecological Complexity* 20:1–10.

Vigerstol, K. L., and J. E. Aukema. 2011. A comparison of tools for modeling freshwater ecosystem services. *Journal of environmental management* 92(10):2403–9.

Viglizzo, E. F., J. M. Paruelo, P. Laterra, and E. G. Jobbágy. 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems and Environment* 154:78–84.

Villa, F., B. Voigt, and J. D. Erickson. 2014. New perspectives in ecosystem services science as instruments to understand environmental securities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369:20120286.

Villamagna, A. M., P. L. Angermeier, and E. M. Bennett. 2013. Capacity, pressure, demand, and flow: A conceptual framework for analyzing ecosystem service provision and delivery. *Ecological Complexity* 15:114–121.

Vis, M., M. River, B. Management, W. L. D. Hydraulics, P. O. Box, and M. H. Delft. 2003. Resilience strategies for flood risk management in the Netherlands. *International Journal of Basin Management* 1(1):33–40.

Vocal Ferencevic, M., and P. Ashmore. 2012. Creating and evaluating digital elevation model-based stream power map as a stream assessment tool. *River Research and Applications* 1416(April 2011):1394–1416.

Vromans, D. C., K. S. Maree, S. Holness, N. Job, and A. E. Brown. 2010. *Biodiversity Sector Plan for the George, Knysna and Bitou Municipalities. Supporting land-use planning and decision-making in Critical Biodiversity Areas and Eclological Support Areas for Sustainable development*. *D*. Knysna.

Vyas, S., and L. Kumaranayake. 2006. Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning* 21(October):459–468.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems : A working hypothesis for a participatory approach. *Conservation Ecology* 6(1).

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience , adaptability and transformability in social-ecological systems. *Ecology And Society* 9(2).

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Island Press.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. Fromentin, O. H. I, and F. Bairlein. 2002. Ecological responses to recent cimate change. *Nature* 416:389–395.

Wheater, H., and E. Evans. 2009. Land use, water management and future flood risk. *Land Use Policy* 26:S251–S264.

Winter, T. C. 2001. The concept of hydrologic landscapes. *Journal Of The American Water Resources Association* 37(2):335–349.

Wolff, S., C. J. E. Schulp, and P. H. Verburg. 2015. Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators* 55:159–171.

Yuan, Y., J. Liu, H. Liu, L. Tan, and H. Liu. 2012. Spatial-temporal variation of ecosystem services in response to land use changes : Case study in the 38 ° N ecological transect of Northern China. *Journal of Food, Agriculture and Environment* 10(April).

Zerger, A., and S. Wealands. 2004. Beyond Modelling: Linking Models with GIS for Flood Risk Management. *Natural Hazards* 33(2):191–208.

Zhao, C., H. A. Sander, and B. Bond-Lamberty. 2015. Quantifying and mapping the supply of and demand for carbon storage and sequestration service from urban trees. *PLoS ONE* 10(8).

Zhou, Y., N. Li, W. Wu, and J. Wu. 2013. Assessment of provincial social vulnerability to natural disasters in China. *Natural Hazards* 71(3):2165–2186.

Ziegler, A. D., T. W. Giambelluca, D. Plondke, S. Leisz, L. T. Tran, J. Fox, M. a. Nullet, J. B. Vogler, and D. Minh Troung. 2007. Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow. *Journal of Hydrology* 337(1-2):52–67.

Chapter 7
Appendices

These appendices include

1. **Appendix A:** Supporting information for Chapter 2
    a) Keywords used in literature search in search engine Scopus

Appendix A: Keywords used in literature search in search engine Scopus

- Regulating ecosystem services
- Flood regu*and ecosystem services
- Carbon sequestration and regu *ecosystem services
- Pollination and regu* ecosystem services
- Carbon storage and regu*ecosystem services
- water quality and regu* ecosystem services
- Soil erosion and regu* ecosystem services
- Climate regulation and regu* ecosystem services
- Soil retention and regu* ecosystem services
- Soil stability and regu*ecosystem services
- Natural disaster and regu*
- Water provision and regulating ecosystem services
- Water provision and regu*ecosystem services
- Pest regulation and regu* and ecosystem services
- Disease regulation and regu* ecosystem services
- Waste regulation and regu* ecosystem services
- Air quality and regu* ecosystem services

The search term regu* was used to account for both regulation and regulating