Agrarian change and hydro-social transformations

The socio-natural production of water, risk and inequality in Jambi province, Indonesia

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For Lia

Executive summary

The production of global commodities such as soy, coffee or palm oil has caused a large-scale expansion of agro-industrial plantation systems in many countries of the Global South in recent years. This plantation development has led to substantial alterations in the biophysical environmental, for example, through widespread deforestation. It has also come along with the transformation of local political economies, producing both winners and losers of this agrarian change. Indonesia is a country exemplifying such agrarian change for global production. There, the production of natural rubber, palm oil and pulpwood has led to the establishment of large areas of intensively managed, export-oriented plantation systems. This development is highly contested at local and global levels. It has sparked conflict over access to land and forests areas and also about the loss of tropical biodiversity or the emission of greenhouse gases that spur global climate change.

A topic receiving rather little attention in this context is water. To date, only few studies across the social and natural sciences present insights into the ecohydrological consequences of this agrarian change and the social impacts and dynamics it entails. This doctoral thesis aims to contribute to this gap in literature. For this purpose, it provides in-depth insights from a key region of agrarian change in Indonesia, the Jambi province on Sumatra. It builds on in-depth qualitative case studies and complements these with extensive analyses of ecohydrological measurements and data.

In studying the ecohydrological and social, or "hydro-social", transformation processes in Jambi, the thesis pursues two main aims. First, it aims to investigate how agrarian change has contributed to a reconfiguration of hydro-social relations in Jambi. Therein, it seeks to disentangle the social and environmental processes that have contributed to the production of new water related risks and social inequality. Second, on a conceptual level, this thesis aims to assess different conceptual and methodological approaches to a more integrated study of environmental risk. For this purpose, it analyzes how the conceptual frameworks critical realism and relational dialectics may help to study the interactions and feedback processes between water flows and local societies. Finally, this thesis explores different modes of combining research data on environmental perceptions and local ecological knowledge with natural science measurements.

In total, this thesis comprises five articles and manuscripts that explore different aspects and dynamics of the hydro-social transformations in the context of agrarian change in Indonesia. Together, they demonstrate that the recent agrarian change has contributed to the production of multiple, interrelated water relates risks, such as water scarcity, flooding and the risk of peat fires. The thesis finds that mutual changes in material water flows, people's cultural attachments to water and their material and discursive practices of engaging with water provide key explanations for the production of water risks in Jambi. In particular, an increasing representation of flooding as an obstacle to economic development and changes in soil hydraulic properties and plant transpiration rates associated with forest conversion constitute key processes in this development. They help explain a trend towards increasing extremes in river and groundwater water levels as well as an increasing depiction of water as risk and hazard.

The impacts of these newly produced water risks, as this thesis shows, are distributed highly unevenly across society. Flooding, for example, is increasingly managed through technical interventions in water

flows and thus redistributed at the local level. In consequence, it often affects those people not able to invest in costly flood control measures. In particular, food crop farmers and other smallholder farmers cultivating wetlands are suffering from a decreasing capability to benefit from their land. As flooding, water scarcity and fires frequently threaten their fields and plantations, their land use options are gradually decreasing. Together, as this thesis shows, such developments lead to the fact that access to and protection from water have turned into sources of local contestations and inequality.

Existing risk mitigation strategies tend to exacerbate these dynamics further. As peat drainage causes large amounts of greenhouse gas emissions, water in Jambi has also turned into contested resource at the global level. Multiple transnational initiatives have recently been found to promote alternative, low carbon development pathways in Jambi's peatlands. These approaches however strongly conflict with local land use imaginaries and local sources of livelihoods, which mainly rest on incomes from export-oriented plantations. Climate mitigation initiatives that materialize in new land use policies and agreements in Jambi thus end up further restricting smallholder peat farmers in the ways they can cultivate their land.

Finally, on a conceptual level, this thesis shows how both critical realism and relational dialectics present useful frameworks for more integrated studies of environmental risk. They allow reconstructing the processes contributing to risk production and are open towards the integration of both environmental and social processes in risk analysis. While critical realism provides a strong framework enabling the integration of both social and natural science methods, relational dialectics provides a particularly dynamic and socially sensitive framework to the study of risk. Yet, both approaches also have their limitations, something that is discussed in this thesis, too. Finally yet importantly, this thesis presents and discusses different ways of combining local and scientific knowledge in the study of environmental risk. It works out how such integration can provide for a more holistic, practically relevant and socially sensitive understanding of environmental risk and reflects on the conditions necessary to achieve such knowledge integration.

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Acronyms

ANT	Actor-Network Theory
ASEAN	Association of Southeast Asian Nations
BD	Bulk density
BMKG	Badan Meteorologi, Klimatologi, dan Geofisika (Indonesian Center for Meteorology, Climatology and Geophysics)
BPS	Badan Pusat Indonesia (Statistics Indonesia)
BRG	Badan Restorasi Indonesia (Indonesian Peat Restoration Agency)
COP	Conference of the Parties (to the UNFCCC)
CRC	Collaborative Research Center
CSR	Corporate Social Responsability
DFID	Department for International Development (United Kingdom)
EFFoRTS	Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Collaborative Research Center 990 at the University of Göttingen)
EFForTS-BEE	EFFoRTS Biodiversity Enrichment Experiment
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FOLU	Forest and Land Use Sector
FORCLIME	Forest and Climate Change Program (by the GIZ)
GHG	Greenhouse Gases
GHGE	Greenhouse Gas Emissions
GIZ	Deutsche Gesellschaft für International Zusammenarbeit (German Agency for International Cooperation)
GWT	Groundwater table
ICCFT	Indonesia Climate Change Trust Fund
INDC	Intended Nationally Determined Contributions (to the UNFCC)
IPCC	Intergovernmental Panel on Climate Change
IPB	Institut Pertanian Bogor (Agricultural University Bogor)
ISPO	Indonesian Sustainable Palm Oil (certification system)
KLHK	Kementerian Lingkungan Hidup dan Kehutanan (Indonesian Forestry Ministry)
ECCHR	European Center for Constitutional and Human Rights
ENSO	El Niño-Southern Oscillation
MOEF	Indonesian Ministry of Environment and Forestry
NDC	Nationally Determined Contributions (to the UNFCC)

NGO	Non-governmental organization
PM	Particulate matter
PSI	Pollutant Standards Index
PTPN	Perseroan Terbatas Perkebunan Nusantara (state-owned plantation company)
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RSPO	Roundtable for Sustainable Palm Oil
SDII	Simple pricipitation intensity index
SE	Standard error
SPEI	Standardized Precipitation Evapotranspiration Index
SFB	Sonderforschungsbereich (Collaborative Research Center)
STS	Science and Technology Studies
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
WWF	World Wide Fund for Nature

CHAPTER I: INTRODUCTION

1. Introduction

The production of global commodities such as soy, coffee or palm oil has led to the establishment of large-scale agro-industrial plantation systems across many countries of the Global South in recent years (Hosonuma et al. 2012, Niewöhner et al. 2016, Tramberend et al. 2019, Qiang et al. 2020). This development has come along with deep transformations in both, the biophysical environment and the political economy. Plantations of export crops are often established at the expense of tropical forest areas and result in the loss of local ecosystem functions (Hosonuma et al. 2012, Margono et al. 2014, Austin et al. 2019, Dislich et al. 2016). They also come along with an increasing competition over land and natural resources, producing both winners and losers of such agrarian change (Gerber et al. 2009, Beckert et al. 2014, Li 2014, Pichler 2014, Niewöhner et al. 2016, Dietz and Engels 2020). Understanding both, the social and the ecological implications of agrarian change for global production, and the interactions and feedback processes therein, is hence of local and global importance. It reflects in innumerable scientific, private and political initiatives aiming to understand and govern the consequences of such transformation processes (e.g. COUPLED 2017, NABU 2019, BMZ 2020, Georg-August Universität Göttingen 2020, OPAL 2020, RSPO 2020, UNFCCC 2020).

Indonesia is a particularly interesting case exemplifying such agrarian change for global production. There, the production of natural rubber, palm oil and pulpwood has led to the establishment of large areas of intensively managed, export-oriented plantation systems (Margono et al. 2014, Miettinen et al. 2016, Austin et al. 2019). Pushed through both small and large-scale plantation development, the country has experienced widespread forest and land use conversion (Fearnside 1997, McCarthy 2010, Abood et al. 2014, Li 2014, Clough et al. 2016, Steinebach 2017, Austin et al. 2019). It has turned Indonesia into one of the countries with the highest deforestation rates in the world (Margono et al. 2014, Weisse and Goldman 2020). The pace and extent of this agrarian change causes it to be strongly contested. Inter alia, it has sparked conflicts over access to land and forest areas, the loss of tropical biodiversity and the emission of greenhouse gases, spurring global climate change (Koh and Ghazoul 2008, Danielsen 2009, Potter 2009, Steinebach 2013, Beckert et al. 2014, Pichler 2014, Harris et al. 2015, Brot für die Welt 2019, Greenpeace International 2019, 2020, Meijide et al. 2020).

A topic hardly noticed in this context, is water. This is truly surprising as Indonesia, the "land of thousand islands", is known as a land of water (Boomgaard 2007). Numerous anthropologists have richly described how oceans and the large lowland rivers have shaped the islands histories, cultures and economies (Andaya 1993, 2016, Boomgard 2007, Christie 2007). On the downside, global news frequently report how river pollution, ocean plastic, land subsidence or flooding threaten local development across the country (Lamb 2018, Putz 2018, Rasyadi 2019, Carrubba 2020). Water, in the context of agrarian change, however, has received much less attention, both scientifically as well as politically.

To date, only a few scientific studies have investigated the ecohydrological consequences of agrarian change in Indonesia and Maritime Southeast Asia in general. A few social science studies have reported about villagers complaining about increasing challenges of flooding and water scarcity in plantation-dominated landscapes (Larsen et al. 2012, Merten 2014, Wells et al. 2016). However, the processes contributing to such changes and the social implications they entail are not well understood. Existing natural science studies so far only present fragmented and partly contradictory insights into the topic (e.g. Yusop et al. 2007, Banabas et al. 2008, Comte et al. 2012, Manoli et al. 2018). They have also largely neglected the role of social processes in shaping local water flows.

There is hence a need for more integrated research endeavors that investigate the role of water in the context of agrarian change for global production. Such studies are required to gain more complete insights into the social and ecohydrological consequences of such transformation processes. They may also help to achieve a better understanding of the interactions and feedback processes between water flows and local societies (cf. Lele and Kurien 2011, Di Baldassare et al. 2014). The investigation of such "hydro-social"[1] relations and their transformation in the context of agrarian change in Indonesia is hence what I aim to contribute to with this thesis.

In order to structure and organize my investigation of these hydro-social transformations, I will mainly build on research developed in political ecology and adjacent research fields. Political ecology has a long tradition of critically investigating locally specific interactions between societies and their biophysical environment. It has also richly investigated the production of environmental risk, i.e. the risk of harmful events associated with environmental change. It provides a particularly interesting lens to the study of hydro-social transformations in the context of agrarian change. This is because: first, it allows to capture the interaction of both social and environmental processes. For risk to materialize, it requires both a threatening environmental process or event as well as a vulnerable population (Pelling 2001, Wisner et al. 2003). Second, it allows to investigate hydro-social transformations in a socially sensitive way. The production of risk, as has been shown in previous studies, is often closely linked to the production of social inequality and injustice (e.g. Hewitt 1983, Pelling 2001, Mustafa 2002, Smith 2006).

Guided by the lack of research on water in the context of agrarian change in Indonesia and a political ecology-inspired approach to risk analysis, I pursue two main research objectives in this thesis:

> First, my overarching empirical research objective is to gain a deeper understanding of the ongoing social and environmental transformations in the context of agrarian change in Indonesia. In particular, I aim to investigate how agrarian change for global production has contributed to a reconfiguration of local hydro-social relations. Therein, I strive to understand, which social and environmental processes have contributed to this change and what water-related risks have been produced therein. In addition, I aim to pay close attention to the socially differentiated impacts of these risks and the production of social injustice.

[1] The term "hydro-social relations" has been coined by diverse scholars in the research field of political ecology. Briefly, it has been used to refer to the ways how water and societies interact and influence each other in a process of mutual adjustment (Swyngedouw 2009, Linton and Budds 2014).

Second, in order to better understand the interactions and linkages between social and ecohydrological processes, I aim to assess different approaches enabling more integrated analyses of environmental risk: On a conceptual level, I want investigate the potential of two distinct frameworks to such an endeavor, namely critical realism and relational dialectics. Methodologically, I seek to explore different ways of combining qualitative social research data on environmental perceptions and local ecological knowledge with natural science measurements.

In order to attain these objectives, this thesis builds on 10 months of qualitative field research in a key region of agrarian change in Indonesia. In Jambi province on Sumatra, I conducted field research in two distinct physiographic areas. This helped me to gain insights into locally specific but also into more overarching processes contributing to the transformation of hydro-social relations and the production of risk therein. In addition, I build my investigation on extensive interdisciplinary collaborations with colleagues from the natural sciences. Together we discussed multiple environmental measurements and data to interrogate the ecohydrological consequences of agrarian change, and the large-scale forest conversion in particular.

My fieldwork in Jambi province was guided by the following research questions:

- How has agrarian change transformed local hydro-social relations and what new water-related risks have been produced therein?
- What are the specific multiple biophysical, social, economic and political processes contributing to the production of water-related risks?
- What kind of policies, programs and strategies exist to cope with and/or to mitigate water-related risks[2], and at what levels?
- What are the socio-cultural and economic impacts for local communities? And (how) do these hydro-social transformations contribute to the production of new inequalities and injustices?

The thesis is structured as follows. This first chapter serves as an introduction to the thesis. In the following, I will elaborate on the conceptual and analytical frameworks guiding this thesis, introduce the empirical setting and explain the methodological approach adopted for this research. Chapters II to VI then constitute the main part of this thesis. They comprise five individual articles and manuscripts that my colleagues and I submitted and partly already published in international peer-reviewed journals. All of them constitute stand-alone contributions that provide insights into individual parts of the overarching research objectives and questions posed. Each of the chapters takes up particularly relevant points that emerged during fieldwork in Jambi province and applies conceptual and analytical frameworks that I considered to best expound the empirical problems encountered. The final part of the thesis provides a synthesis of the different articles and manuscripts. It works out key findings, illustrates their scientific contribution to the literature and lays out future research needs.

[2] The different environmental risks described in this thesis are all related to changes in local water flows. Yet, they do not only refer to explicit water risks such as flooding or water scarcity, but also include secondary risks, such as the risk of fire in drained peatlands. Hence, using the term "water-related risks" would be more accurate to describe the type of risks referred to in this thesis. Yet, for reasons of readability, in the following I will abbreviate this terminology and only refer to "water risks".

2. Conceptual framework

In this chapter, I will provide an overview of the conceptual and theoretical frameworks that guided my investigation of the recent hydro-social transformation processes in Jambi province. It consists of two main parts. First, I will briefly introduce the research field political ecology and elaborate how it has shaped my understanding of environmental risk. In the second part, I will then work out two research endeavors that help furthering our understanding of environmental risk, not only in political ecology but also beyond. In the sub-chapters of this second part, I will present the individual conceptual and analytical frameworks employed in chapter II-IV and VI of this thesis.

2.1. Developing a political ecology of environmental risk

2.1.1. Political ecology as a "capacious umbrella term"

Geography is an interdisciplinary research field encompassing both social and natural science sub-disciplines. Yet, the question of how exactly both physical and human geography should or should not be integrated and with what purpose remains a contested endeavor (Goudie 1986, Weichhardt 1993, Turner 2002, Viles 2005, Castree 2012, Goudie 2017, Zimmerer 2017). Political ecology partly emerged from such endeavors and has become a well-established research field in human geography (cf. e.g. Heynen 2013, Turner 2013, Robbins 2012, Loftus 2019, Sultana 2020). It developed from a desire to develop alternatives to what were labeled *apolitical* ecologies in the 1960s and 1970s (Robbins 2012, Bridge et al. 2015). Being a field of "disciplinary transgressions" (Bryant 1999: 148), political ecology has been influenced and developed by scientists from anthropology, sociology, geography and political sciences. Together, these scholars sought to situate environmental risk and degradation into the wider social and historical contexts by working out the societal (power) relations behind environmental knowledge and policies.

Today, political ecology is a broad field of research that covers a wide array of topics, places, methodological approaches and theoretical conceptions (Bridge et al. 2015, Bryant 2015, McCarthy 2017). It stretches along different sub-fields of geography and helps connecting fields such as urban and rural geography, development geography and economic geography (Bryant 1999, Sywngedouw and Heynen 2003, Robbins 2004). Political ecology thus evades a simple definition and rather serves as a "capacious umbrella term" (McCarthy 2017: 1). It is an experimental epistemological project that aims at understanding and critically interrogating specific relationships between societies and their biophysical environment (Bridge et al. 2015). Political ecology can hence better be defined by common commitments and assumptions than by theoretical conceptions or topics of research (Bridge et al. 2015, McCarthy 2017). These commitments include: a *theoretical* commitment to a post-positivist understanding of nature and the production of knowledge; a *methodological* commitment to in-depth, place based research that aims to understand human-environment interactions in their social complexity and historical-geographical context; and finally, a normative *political* commitment to the promotion of a world that is socially and environmentally more just (Bridge et al. 2015, McCarthy 2017).

One of the antecedent research fields that political ecology developed from was hazard research (Wescoat 2015). Hazard research was criticized for being dominated by technocratic and behavioral approaches to risk and for overemphasizing the supposedly "natural" dimension of "natural disasters" (ibid.). Beginning in the 1970s and 1980s, political ecology thus developed alternative approaches to the study of risk. Since then, political ecology scholars, inter alia, have focused on revealing the social root causes of vulnerability and critically analyzing the power relations embedded in risk assessments and policies (e.g. Hewitt 1983, Watts 1983, Blaikie et al. 1994, Mustafa 1998, 2002, Pelling 1999, Collins 2009, Ribot 2014, Simon 2014, Neale et al. 2016, Oliver-Smith et al. 2017). They have also started to deconstruct the role of risk discourse and representation in the shaping of unequal conditions of risk and vulnerability (e.g. Emel and Huber 2008, Rebotier 2012, Jones et al. 2014). Briefly, political ecology has worked out how risks are produced through historically and geographically specific political, social and economic processes and structures (Wescoat 2015).

2.1.2. The socio-natural production of environmental risk

Building upon the manifold interconnections and feedbacks between social and environmental processes in the production of risk, political ecology has shaped an understanding of environmental risks as "socio-naturally produced". "Produced" in this context refers to Neil Smith's (1984: 32ff) thesis on the "production of nature". Therein, Smith argued that "nature" is a temporary outcome of a complex and dynamic historical-geographical process (Swyngedouw 2015: 20). Nature and risk are thus rather "made" through specific human practices, than naturally a given[3] (Loftus 2017).

In the following, I will expand on the socio-natural production of environmental risks in more detail, drawing on literature in political ecology and related research fields. For this purpose, I will outline five theoretical arguments and reflections that help explain the different ways in which social and biophysical processes interact in the production of risk. During the research process, these arguments and reflections helped me orientate myself during field research. Together with my empirical research findings, they also guided my choice of specific conceptual and analytical frameworks used for the different manuscripts and articles across chapters II-VI.

First, decades of risk research have shown that disasters are typically caused by complex intermixtures of social and geo- or biophysical processes (e.g. Blaikie et al. 1994, Brookfield 1999, French et al. 2020). Hence, risks today are widely conceptualized as resulting from a combination of environmental hazards and vulnerability (Wisner et al. 2012: 24*)*. Hazards therein are understood as environmental events and processes potentially harmful (Wisner et al. 2012: 24). Yet, environmental hazards are often ambiguous in nature. Flooding or volcanic eruptions, for example, may entail opportunities such as carrying fertile sediments and ashes as well as posing dangers through being a potentially destructive force. Whether an environmental event is perceived and represented as a hazard is thus clearly dependent upon the local context (Pelling 2001). It may also differ across different social groups and

[3] While Neil Smith (1984) mainly referred to nature as being "socially" produced, multiple political ecology scholars have developed his argument further. They started referring to a "socio-natural" production of nature to also acknowledge the active role of the biophysical environment in the shaping of specific types of nature (e.g. Swyngedouw 2004) (for more details on this argument, see chapter I: 2.2.2).

change over time (ibid.). This perception is clearly linked to vulnerability. Vulnerability, in the broadest sense, is one's individual "susceptibility to harm"[4] (Adger 2006: 268). It is determined by social, political, economic structures and historical processes that shape the degree and reliability of different people's access to different kinds of resources (Wisner et al. 2012: 22ff, Ribot 2014). Such resources may include agricultural land or water but also political power, wealth or safe housing (Wisner 2012: 27). Whether or not disasters – small or large-scale events resulting in loss and damage – do materialize is thus clearly dependent upon specific socio-natural configurations (Wescoat 2015). Without a hazard there is no disaster and without vulnerability the hazard loses its hazardousness (Pelling 2001).

Second, environmental hazards are likely the product of both social and biophysical processes. Nowadays, hardly any biophysical process can be claimed to occur independent of human alteration. Large parts of the earth's surface are transformed by human settlements, agricultural production systems or mining activities (Crutzen and Stoermer 2000). Moreover, anthropogenic changes in global processes such as climate change, biodiversity loss, or the nitrogen cycle impact our biophysical environment across local and global scales (Rockström et al. 2009). In general, most biophysical processes are extremely complex and interconnected, making it hard to discern individual causal processes (van Dijk et al. 2009, Pattison and Lane 2012). Anthropogenic land use conversion or climate change, for example, will always interact with local physiographic conditions. Bare soils following deforestation may thus, combined with intensive tropical precipitation and dense clayish soils, result in sharp increases in surface-runoff and eventually flooding (Bruijnzeel 2004).

Third, environmental risks need to be understood in their historical and geographical embeddedness (Watts 1983, Bankoff 2003). Much research has shown that the root causes of vulnerability often lie in unequal histories of colonization, economic development and marginalization (e.g. Hewitt 1983, Watts 1983, Blaikie et al. 1994, Hewitt 1997, Mustafa 1998). Colonial projects, for example, have often introduced new legal systems redefining land and property (Kunz 2016). They have also established different systems of agricultural production, thereby creating lasting legacies in local ways of managing land or water (D'Souza 2006, Ley 2018). Vulnerability thus needs to be understood as constantly "in-production" (Simon 2014). It is perennially shaped and reshaped by ongoing political, social and economic developments (ibid.). A the same time, the way how a society perceives and interprets environmental risk depends on imaginaries and paradigms prevailing during specific historical episodes (Jasanoff 1999, Oliver-Smith 2004). The idea of human emancipation and self-realization during the enlightenment, for example, was closely linked to the perception of nature as unruly and hazardous (Oliver-Smith 2004).

This leads us to the next argument that, fourth, the materiality (biophysical properties or conditions) of things and their social meaning may interact in the production of environmental risk. On the one hand, specific framings of nature and risk determine how environmental processes and conditions are

[4] The conceptualization of vulnerability in this thesis builds on a context-oriented or processual view of vulnerability (cf. O'Brien et al. 2007, Ribot 2014, Gibb 2018). Different scholars have highlighted the importance of distinguishing two opposite approaches to a conceptualization of vulnerability: An outcome-oriented approach to vulnerability that considers vulnerability as a linear *outcome of* environmental change and a context-oriented approach to vulnerability. The latter investigates how specific social, political, economic and structural-historical processes shape vulnerability. Such conceptualization of vulnerability thus considers people to be vulnerable *to* undesirable outcomes (Ribot 2014).

managed (Oliver-Smith 2004, Rebotier 2012). The enlightenment was, for example, closely linked to the idea of the control and the use of nature (Oliver-Smith 2004, Linton 2010). In addition, decisions to frame environmental processes in terms of risk, or to blame specific social groups for causing disaster, actively shape risk prevention, assessment and response policies (Jasanoff 1999, Collins 2009, Rebotier 2012, Simon and Dooling 2013, Neale et al. 2016). Such risk policies in turn determine the material conditions of vulnerability across different social groups (Rebotier 2012). On the other hand, the physical experience of disaster actively shapes societies, too (Bankoff 2003: 179ff). For billions of people, disasters are an integral feature of daily life (ibid.). Disasters influence local cultures, political structures and economic systems (ibid.). The specific material properties of environmental processes and events play an important role therein (Fitzsimmons 1989, Bakker 2003, Bakker and Bridge 2006, Whatmore 2006, Bear and Bull 2011). They may enable or constrain how social relations unfold, present sources of unpredictability, unruliness or even resistance to human modification (Bakker and Bridge 2006).

Fifth, the production of environmental risk is often linked to the production of inequality. Disasters are often considered to be revelatory events that expound and reinforce the existing relationships among environments, cultures, politics and power (Hewitt, 1983, Oliver-Smith 1986, Pelling 2001, Claus et al. 2015, Hallegatte et al. 2020). Such is for example the case if poor people cannot afford safe housing, dwell in dangerous environments and are then disproportionately affected by hazardous environmental events (Smith 2006). Moreover, risk mitigation policies are often considered to reinforce social inequalities (Mustafa 1998, 2002, Collins 2009, Simon and Dooling 2013). This is because vulnerability often has a relational component (Taylor 2013). It means that "the relative security of some social groups is achieved through the production of insecurity among others" (Taylor 2013: 318). Such linkage is often explained by the close relation between social power relations and knowledge production (Foucault 1980, Forsyth 2003, Gaillard and Mercer 2013). As a result, scientific or expert knowledge is often prioritized in risk assessments compared to, for example, local knowledge (Forsyth 1996, 2003, Gaillard and Mercer 2013). In turn, this may lead to the fact that political interpretations of risk and vulnerability often remain disconnected from the lived experience of vulnerable people (Simon and Dooling 2013, see chapter V). It may also result in the fact that poor people are blamed for settling in hazardous environments or contributing to environmental degradation. This even being the case if there is a lack of solid assessments of why they do so and whether the latter is really the case (e.g. Fairhead & Leach 1998, Calder and Aylward 2000, Forsyth 2003, Benjaminsen et al. 2006, Hofer and Messerli, 2006, Kooy and Bakker 2008, Benjaminsen 2015). Such misrecognition and a lack of political participation may result in marginalization which is "the exclusion of certain individuals and groups from economic, social or political resources" (Pelling 2001: 179). It is considered the main root cause of vulnerability (cf. also Hewitt 1983, Pelling 2001, Wisner et al. 2012).

Capturing this socio-natural production of environmental risk requires conceptual frameworks and analytical lenses. In the following, I will hence introduce the frameworks and lenses chosen to order and structure the investigation of these complex interactions between societies and their biophysical environments. Each of the frameworks focuses on different arguments and reflections listed above. Together, they address two main research endeavors in risk research, in political ecology but also beyond. These are: first, the integration of social and environmental processes in the analysis of risk and second, the production of inequality and injustice in the context of agrarian change.

2.2. Integrated analyses of risk production – overcoming the analytical divide

As illustrated above, interrogating environmental risk in the context of agrarian change clearly requires integrated analyses: studies that take into account the interactions and feedback mechanisms between biophysical and social processes in risk production and the material and discursive dimensions of risk. Already in 2004, Oliver-Smith argued that a truly integrated analysis of risk needs to investigate: first, "the general contributions of the cultural construction of nature to the social production of disaster", second, how the "conditions that characterize vulnerability are inscribed in an environment" and third, the "relationship between the cultural interpretation and the material world of risk" (Oliver-Smith 2004: 11-12).

Yet, studies uncovering such socio-natural entanglements and intermixtures still present minority work: much risk research today remains divided into those studies that focus their analysis on the biophysical hazard and those that focus on the causes of vulnerability (Rebotier 2012, Wisner et al 2012, Di Baldassare et al. 2014, Ribot 2014, Donovan 2017). This is also the case in political ecology, which has often focused rather strongly on the social processes of risk production. In consequence, the role of the biophysical environment in shaping socio-natural conditions has often been sidelined (Vayda and Walker 1999, Walker 2005, Wescoat 2015). Two major challenges continue inhibiting more complete and integrative approaches to the study of environmental risk.

First, even those studies pursuing integrated forms of risk analysis are often accused for not being integrative enough. This is for example the case if other disciplines are only integrated as external forces affecting the subject of study (Di Baldassare et al. 2014). (Qualitative) Social science studies are often critiqued for paying too little attention to material complexities and ecological dynamics. Natural science studies or coupled system approaches, in turn, are blamed for trying to integrate humans into models-thinking, thus ignoring social complexity, human agency and social power relations (Tolia-Kelly 2011, Di Baldassare et al. 2014, Spiller et al. 2015, Stone-Jovicich 2015, Wescoat 2015, Wesselink et al. 2017). These problems are closely related to the inherent society-nature dualism present in much risk research. Artificially separating the world in to a "social" and a "natural" realm, it has been argued, limits our understanding of the ways in which society and nature interfere and are, in fact, inseparable (Castree 2005: 221f).

Second, the prevalent divide between positivist and constructivist epistemologies is often deemed another barrier to collaborations between the natural and the social sciences in risk analysis (Jasanoff 1999, Lele and Kurien 2011, Di Baldassare et al. 2014, Krüger et al. 2016, Wesselink et al. 2017). While positivist approaches consider risk "as an objective hazard that exists and can be measured independently of social and cultural processes" (Wisner et al. 2004: 18), constructive approaches take risk as being "refracted in every society through lenses shaped by history, politics and culture' (Jasanoff 1999: 139). Based on such fundamentally differing conceptualizations of risk, both are often linked to divergent objectives in risk analysis. The former typically focus their analysis on the material conditions of risk. The latter, on the contrary, emphasize the need to uncover differing representations and framings of risk, including the social power relations behind them (Jasanoff 1999).

In the following, I present two conceptual frameworkes that are considered particularly useful to overcome some of these challenges to an integrated analysis of environmental risks (Stone-Jovicich 2018, van Koppen 2017, Donovan 2017). These are critical realism and relational dialectics. Both of them aim to integrate the biophysical environment in a political ecology-inspired study of risk. Critical realism contributes to overcoming the divide between positivist and constructivist epistemologies. Relational dialectics contributes to overcoming the society-nature dualism. These two approaches build the basis for the articles and manuscripts presented in the first part of the thesis (chapters II-IV). In this chapter, I will elaborate the main theoretical foundations, recent developments and wider application of these two approaches. Chapters II-IV will then apply these frameworks to the study of specific empirical cases.

2.2.1. Critical realism and local knowledge integration

Critical realism criticizes the divide between positivist and constructivist schools of thought in risk research. Contrary to prominent claims in literature, critical realism argues that both approaches are in fact well reconcilable and together can produce a better understanding of risk production. Critical realism constitutes the framework used for chapter III on "Flooding and land use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry".

Critical realism is a philosophy of science that was originally developed by Roy Bhaskar in the 1970s and 80s (Fletcher 2017). His main allegation towards the natural sciences was that they were committing an "epistemic fallacy" (1998: 27) of reducing ontology to epistemology. They were thus limiting "reality" to what can be empirically known (Fletcher 2017, Yeung 1997). Bhaskar emphasized the need to treat ontology and epistemology in separate and presented an alternative version of a realist philosophy. His *critical* realist philosophy acknowledges the existence of a reality independent of human consciousness but argues that human knowledge is always fallible, partial and socially constructed (Forsyth 2011, Nastar et al. 2018). Hence, it is only able to capture a small part of a deeper and vaster reality (Yeung 1997, Fletcher 2017). Following the logic of critical realism, there is no need for a dichotomy between positivist and constructivist approaches to risk (Ribot 2014). This is because one may distinguish between a constructivist ontology and a constructivist methodology (ibid.). The latter should then be considered as a way of understanding situated knowledge which, however, does not conflict with a realist ontology, which assumes that there are "real" conditions and causes of vulnerability (Leach 2008, Ribot 2014).

To illustrate this, a critical realist ontology differentiates between three levels of reality: the *empirical* level of events or objects, which can be observed, experienced and studied; the *actual* level within which events occur whether or not we experience them and the *real* level at which "causal mechanisms" exist (Fletcher 2017). These mechanisms are properties in an object or structure that act as causal forces to produce events at the empirical level (ibid.). Importantly, almost all events at the actual level are considered to occur in open systems (Bhaskar 2010). They must thus be conceived as co-determined by a multiplicity of causal mechanisms (ibid.). Moreover, critical realism recognizes that the empirical level, the way we measure and interpret things, can be causal as well (Fletcher 2017). The primary goal of critical realism then is to explain empirical socio-natural phenomena, such as environmental risks, through reconstructing these mechanisms (Yeung 1997, Fletcher 2017). This process of abduction (cf. Castree 2006: 116) is aimed at through the integration of different knowledge areas (Bhaskar 2010: 4f).

A particular strength of critical realism is its ability to enable collaborations between qualitative social sciences and quantitative natural sciences. It can build on positivist research - though recognizing that science itself is socially constructed - while also acknowledging that framing and discourse shape human behavior and may have material consequences (Ribot 2014). Due to this ability critical realism has become adopted as an important philosophy behind much political ecology work during the 1980s and 1990s and is the main philosophy behind the so-called "critical political ecology" (Forsyth 2001, 2003). A main aim behind the development of a critical political ecology was to integrate an awareness of the social construction of sciences with a realist understanding of the environment and to thereby challenge existing beliefs about the separation of environmental science and politics (Forsyth 2001, 2003).

A critical political ecology of environmental risk today pursues two main aims. First, it may use a post-structuralist lens to work out how environmental science and political processes are mutually embedded (Forsyth 2003). Much critical political ecology work, for example, seeks to deconstruct historical, political and social relations behind supposedly apolitical scientific environmental explanations of environmental degradation and risk (Forsyth 2001). The institutional and power dynamics elevating scientific knowledge over other types of knowledge are a common concern in this type of research (Gaillard and Mercer 2013, Stone-Jovicich 2015). Scientific explanations of environmental degradation and risk production are often critiqued for not representing the interests of groups not involved in the science process. They are thus criticized for providing only partial and socially constructed insights into complex socio-natural processes. Such incomplete environmental explanations may frequently run the risk of exacerbating environmental crisis and strengthening social injustices (Blaikie and Brookfield 1987, Leach and Mearns 1996, Forsyth 2003, Hofer and Messerli 2006, Benjaminsen et al. 2015).

Second, a critical political ecology of environmental risk may also aim to construct new, alternative explanations of environmental degradation and risk production (Forsyth 2001, 2003). Such explanations according to critical realism can only be achieved through the combination of different knowledge areas (Nastar et al. 2018). This is because, as stated above, all empirical phenomena are considered to be co-determined by a multiplicity of causal mechanisms (Bhaskar 2010). critical political ecology in particular aims to integrate local and scientific knowledge areas (Forsyth 2001, 2003). Local knowledge is often gained through personal empirical observation and interpretation of the local environment (Gaillard and Mercer 2013, Berkes et al. 2000). Combining it with scientific knowledge is considered to have two main benefits in the research process. First, it may help empowering social groups and environmental perspectives previously not represented in science. It may thus help address the needs of marginalised or poor communities (Forsyth 1996). Second, local knowledge is considered to usefully complement scientific knowledge because it: also exists in areas where little scientific knowledge exists, is often the only information about past land use and is based on long-term, holistic and repeated observations across a variety of places (Fabricius et al. 2006, Usher 2000, Pierotti and Wildcat 2000, Aikenhead and Ogawa 2007). The overall aim of critical political ecology then is to construct new explanations of risk production that are biophysically more accurate, socially more just and practically more relevant in local contexts (Forsyth 2001, 2003).

This is what chapter III of this thesis aims at in the case of flood risk in Jambi province. The linkage between land use conversion and flood risk is a highly contested research endeavor among both social and natural science scholars (e.g. Hofer 1993, van Dijk et al. 2009). Hence, multiple scholars have called to integrate local people's values and perceptions in the analysis and evaluation such interlinkages (e.g. Lele and Kurien 2011, Di Baldassare et al. 2014, van Noordwijk et al. 2016). Following this need, chapter III integrates local ecological knowledge with scientific data and measurements in order to achieve a more holistic and socially sensitive understanding of the production of flood risk in Jambi province.

2.2.2. Relational dialectics and the study of hybrid water

The second conceptual framework to an integrated study of environmental risk are relational dialectics. They contribute to overcoming the nature-society dualism present in much risk research. Relational dialectics constitutes the framework for chapter II: "Water scarcity and oil palm expansion: social views and environmental processes" and chapter IV: "From rising water to floods: disentangling the production of flooding as a hazard in Sumatra, Indonesia".

As laid out above, environmental risks are neither purely natural nor cultural and are both material and symbolic (Oliver Smith 2004, Donovan 2017). Political ecology has recognized this intertwinement of society and nature by conceptualizing risk and vulnerability in more relational terms. Rebotier (2012: 392), for example, conceptualizes risk as "a situated production (in time, space and society) in both material and discursive terms" and Simon (2014: 1199) argues that vulnerability needs to be conceptualized as a "recursive and relational process that is always in production and inscribed unevenly over time and space". Yet, these studies continue to lack a proper engagement with environmental processes and events in their analysis. Contrary to risk and vulnerability, "nature" is not conceptualized in relational terms but rather remains an external force or a passive substratum that is transformed through social processes (cf. Rebotier 2012, Simon 2014). Different relational approaches to nature, which developed since the early 1990s, could clearly benefit such risk analysis (Castree 2005).

One of these approaches that became popular in political ecology research and in particular in the political ecologies of water, are the so-called "relational dialectics" (Harvey 1996, Linton 2010). Relational dialectics[5] are rooted in the historical-geographical materialism developed by David Harvey (1983, 1996). In his work, David Harvey (1996: 176ff) worked out a twofold intertwinement between social and ecological conditions. First, he argued that all ideas of nature get mobilized for specific purposes. By illustrating the breadth of different ideas of nature and how to manage it – for example through "sustainable development" or "nature conservation" – he showed how these ideas are simultaneously arguments about nature as well as arguments about specific socio-political programs. Yet, such an intertwinement between ecology and politics on the discursive level, he argued, is not sufficient for understanding socio-ecological change. He thus, secondly, emphasized the need to integrate such findings with insights from historical-geographical materialism. Not only arguments

[5] partly also referred to as "new dialectics" (Castree 2005: 232ff)

about but also any transformation *of* ecological conditions, he claimed, would always reflect a particular set of social relations, resulting in the fact that "created ecosystems tend to both instanciate and reflect, therefore, the social systems that gave rise to them" (Harvey 1996: 185).

Eric Swyngedouw in his work on the production of the Spanish waterscape (1999, 2004, 2014, 2015) developed this argument further. He criticized that many Marxist scholars would overemphasize the importance of social relations and render nature only "as the substratum for the unfolding of social relations" (Swyngedouw 1999: 446). Insisting on the "social production of nature" (Smith 1984: 49ff) , as Swyngedouw argued, suggests that social relations ultimately determine the production process. Swyngedouw complemented Harvey's approach to society-nature relations by building on the argument of Latour (1994) and Haraway (1991) that nature is a "hybrid" thing. Nature, as well as most other things, such as water, food, computers or urban areas, they argued, are partly social, partly natural. They are intermediaries that "embody and express nature *and* society" (Swyngedouw 1999: 445, original emphasis). This notion opens up for integrating both materiality and meaning in the analysis of nature. In fact, the very essence of nature is considered to be co-produced by both its biophysical properties and its cultural and symbolic meaning, which is expressed through representation, discourse or cultural practices. Water, for example, can become a border, a territorial object, a resource for regeneration, a means of nation-building or simply the chemical formula H_2O (Hamlin 2010, Linton 2010, Barnes and Alatout 2012, Boelens 2014).

Importantly, Swyngedouw built his notion of hybridity on the principle of internal relations (Ollmann 1993, Harvey 1996). He argued that the properties of things like nature only emerge as a function of their relations with other things and phenomena (Linton and Budds 2014). Change, from this perspective "does not happen *to* things but *among* things" (Linton 2010: 29). Building on this notion of internal relations, implies accepting that the very properties of hybrid things can only be approached through understanding the processes of their becoming (Swyngedouw 1999). A relational dialectical approach to nature hence builds on Lefebvre's (1999) ontological priority of process and flux. That is to say that the approach's prior aim lies in the investigation of the historical-geographical processes that contribute to the production of specific forms of nature or socio-ecological conditions, for example risk (Harvey 1996, Swyngedouw 1999, Castree 2005, Bakker & Bridge 2006).[6]

In addition, Swyngedouw (2004) follows Harvey (1996) in arguing that environmental transformation almost never occur in a non-contradictory (i.e. stable) way. They always produce unintended ecological consequences (Swyngedouw 2004). Socio-ecological change, Swyngedouw posits, is inherently conflict-ridden. It always creates both enabling and disabling social and environmental conditions (ibid.). In his work Swyngedouw, for example, showed how the mutual constitution of water politics, engineering and water culture in Spain contributed to the production of new social inequalities (1999, 2004, 2014, 2015). A relational dialectical examination of water – or other natural resources – thus also requires

[6] Another famous approach to this hybridity is the Actor-Network-Theory (ANT), which developed within the field of science and technology studies (STS). Major differences between relational dialectics and ANT lie in the fact that ANT considers the relations between society and nature as external. ANT thus considers hybrid things to develop as a product out of encounters *between* nature and society. Moreover, ANT focuses rather on the detailed description of socio-natural hybridity than looking for the processes contributing to the production of that hybridity (Swyngedouw 1999, Castree 2005, Bakker and Bridge 2006) (see Greenhough 2017 for a more detailed description of ANT).

examining how water and its circulation internalizes and expresses politics or political economic change as well as the tensions and contradictions emerging in socio-ecological change (Bakker and Bridge 2006, Linton and Budds 2014).

This notion of socio-natural[7] hybridity of water has encouraged many political ecology scholars to explore specific configurations of the "hydro-social" cycle (Swyngedouw 2009). They have used the hydro-social cycle as an analytical framework to explore how society and water shape each other both materially and discursively in a process of mutual adjustment. Thereby, they have highlighted how water plays a positive role in social formations, the power relations embedded in local water flows as well as how water and people are not only related in a material sense but also in experiential, cultural and metaphorical ways (e.g. Bakker 2003, Baviskar 2003, Budds, 2009, Swyngedouw 2009, Debanné 2013, Barnes 2014, Boelens 2014, Linton and Budds 2014, McDonald 2014, Mollinga 2014, Wilson, 2014, Acharya 2015, Mills-Novoa 2017).

Such a relational dialectic perspective on socio-nature and hybrid water provides multiple strengths for an integrated analysis of the production of water risks. In particular, its analytical focus on the processes of production makes relational dialectics well-suited to explain the emergence of new water risks. It also helps to discuss specific ideas of nature, for example as hazard. Surprisingly, however, such relational approaches to nature have rarely been explicitly associated with risk studies (Baldassare et al. 2014, Jones et al. 2014, Donovan 2017). This, although its usefulness for study of risk, for example of flood risk dynamics, is well recognized (e.g. Baldassare et al. 2014, Jones et al. 2014, Donovan 2017).

This is what is done in chapter IV of this thesis. It uses relational dialectical thinking about water and specifically the analytical framework of the hydro-social cycle. It questions how today's notion of flooding as a hazard has come to be produced and interrogates the role of agrarian change therein. Chapter II equally uses the framework of hydro-social cycle but in a slightly different way. It uses the framework as an explanatory tool to make sense of diverging villager's perceptions of the hydrological impacts of oil palm plantations and to emphasize the political dimensions of water in the context of agrarian change.

2.3. Environmental risk and justice

2.3.1. The need for an environmental justice perspective

As outlined above (chapter I: 2.1.2), environmental risks often reflect and exacerbate social inequality. Political ecology research has a long tradition in documenting and criticizing the production of such inequalities (Bridge et al. 2015). Yet, despite its clear normative stance and its strong opposition to the conditions of uneven development, political ecology has repeatedly been criticized for engaging too

[7] The terms "socio-natural" and further below the term "hydro-social" are partly written with or without hyphen in literature. In particular scholars taking a relational dialectical approach to nature, prefer to omit the hyphen in order to illustrate the inseparability of society and nature. This thesis, however, in its majority uses the spelling with hyphen in order to accommodate all chapters under a common use of terminology. Only chapter IV omits the hyphen, as it has been published as such.

little with normative theories (Olson and Sayer 2009, Walker 2009, Svarstad and Benjaminsen 2020). Frameworks and concepts developed in research on environmental justice may thus fruitfully complement political ecology research. They may help to understand the specificities of the inequalities produced and to describe and explain why these are considered unjust (Olson and Sayer 2009, Walker 2009, Svarstad and Benjaminsen 2020).

Justice analyses have become even more important as environmental justice concerns are increasingly operating at a global scale (Sikor et al. 2014). Agricultural production of global commodities, for example, has increasingly reconfigured the geographies and dynamics of environmental (in)justice (ibid.). Inter alia, this is illustrated by innumerous land conflicts between indigenous people and transnational companies (e.g. Gerber 2011, Steinebach 2013). At the same time, large-scale land use conversion in the Global South has contributed to a growing adoption of discourses and governance mechanisms associated with the search for socially just and environmentally sustainable development pathways (Brown an Getz 2008, Marston 2013, Martinez-Alier 2014, Sikor et al. 2014, Pye 2019). They include international organization and conventions such as the Climate Justice Alliance or the United Nations Declaration on the Rights of Indigenous Peoples as well as the development of private sector fair-trade certification schemes. This twofold intertwinement between agrarian change for global production and environmental justice concerns creates the need for solid scientific frameworks that help to evaluate and critique the (in)justices produced therein.

The capabilities approach to justice is a particularly well-suited analytical framework for investigating the production of injustice in the context of agrarian change. It is hence used as a framework for chapter VI of this thesis. In the following, its origins, main arguments and strengths are depicted. Chapter VI then uses the capability approach to evaluate justice in current policies that aim at mitigating climate risks caused by agricultural production on peatlands.

2.3.2. The capabilities approach to justice

Environmental justice research evolved relatively independent from political ecology. It developed in reaction to concerns regarding the inequitable distribution of toxic waste in poor African-American communities in the United States of America in the 1980s (Walker 2012). Back then, distributions of environmental risk and governmental protection were often considered to express the larger reality of socio-economic and cultural inequity[8] (Schlosberg and Collins 2014). Early justice research hence mainly focused on distributive approaches to justice (Schlosberg 2007: 12f). These, following John Rawls' *A Theory of Justice* (1971), are concerned with the rules that govern the distribution of natural and social 'primary goods', such as health, income, power, or civil rights (Schlosberg 2007: 12f). Starting in the 1990s, criticism of such a one-sided conceptualization of justice arose (ibid.). Distributive justice alone, it was argued, would lack a proper engagement with the underlying causes of maldistribution (Young 1990, Fraser 1997). Both, Young and Fraser then contributed to the development of two further dimensions of justice. In particular, they argued that the causes for distributive injustice often lie in the

[8] The terms "equity" and "inequity" are typically invoked to refer to justice in distributive terms. The term "justice", in contrast, is used in a broader sense. It also includes justice dimensions concerning political participation and social misrecognition (cf. e.g. Schlosberg 2007: 25, Klinsky et al. 2016).

lack of social and political recognition (Schlosberg 2007: 13ff). Besides discussing unjust patterns of distribution, any examination of justice thus needs to include discussions of the structures, practices, rules, norms, languages and symbols that lead to institutional subordination and misrecognition of certain social groups (Young 1990, cit. in Schlosberg 2007: 15). Procedural justice was introduced as third dimension of justice. It defines justice as fair and equitable institutional processes of a state (Schlosberg 2007: 25ff). Converting recognition into practices of political participation is clearly a prerequisite for justice (ibid.). Yet, procedural justice is not only a condition *for* social justice but also an element *of* social justice as inequity and misrecognition may hinder real political participation (Young 1990, cit. in Schlosberg 2007: 26).

The capabilities approach to justice links these three justice dimensions – distributive justice, justice as recognition and procedural justice – and has therefore become one of the most influential theoretical approaches to justice (Schlosberg 2007, Olson and Sayer 2009, Walker 2009, Edwards et al. 2016). The capabilities approach was developed by Amartya Sen (1993, 1999, 2004, 2009) and Martha Nussbaum (1993, 2000) and was intended as a broad normative framework for the evaluation and assessment of individual well-being, development and justice (Robeyns 2005). Amartya Sen, in line with Fraser (1997) and Young (1990), criticized that the traditional distributive approach to justice by John Rawls would overemphasize the distribution of primary goods in the evaluation of justice (Sen 2009). Yet, Sen's critique of Rawls was a different one than that by Fraser and Young. Sen argued that justice should primarily be judged on the basis of how the distribution of primary goods affects people's well-being (Schlosberg 2012). Primary goods therein, should, at best, be seen as means to "valued ends" of human life (Sen 2009: 234). Evaluations of justice, according to Sen, should then be judged based on the freedom a person has to choose the life he or she wants to live (ibid.). In other words, he insisted on an "open valuational scrutiny for making social judgments" (Sen 2004: 333). According to Sen, the freedom to effectively being able to choose between different *beings* – e.g. being healthy, being well-educated – and *doings* – e.g. working, reading, voting –, are clearly significant for human well-being (Robeyns 2005). These different kinds of freedoms, from which a person may choose a combination, are referred to as "capabilities" (Sen 2009: 231ff). Whether or not these can benefit one's personal well-being is dependent upon personal, social, environmental conversion factors, for example reading skills, public policies, social norms, or geographical conditions (Robeyns, 2005). By evaluating justice in terms of capabilities, the capability approach also encompasses justice dimensions of recognition and procedural justice: both are necessary to convert resources and assets into valued functionings, i.e. realized capabilities (Robeyns 2005, Sen 2004, Schlosberg 2012). Deprivations and injustice, the capability approach concludes, arise from a lack of capabilities to avoid those deprivations (Sen 2004: 335).

In the context of agrarian change for global commodity production, the capability approach offers a number of strengths in order to evaluate and explain the production of injustice. First, the capability approach to justice is not only well-suited for the evaluation and description of injustice. It may also help to explain the production of specific vulnerabilities. A reduction of capabilities clearly increases a person's overall vulnerability. This is because it might reduce a person's capacity to cope with or adapt to disasters, for example, if their capabilities to choose between different sources of livelihood or their access to goods and resources are reduced. Second, the capability approach takes into account the environment for human functioning (Schlosberg 2012). It acknowledges that environmental conversion factors may either enable or constrain human functioning (ibid.). Thereby, the capability approach allows to evaluate reductions in people's well-being that are caused by environmental risks. Third, through its outcome-oriented focus the capability approach not only serves to assess individual well-being, but can also be used as a normative guideline to evaluate justice in specific policies or projects (Schlosberg 2012). This may include different types of environmental or risk mitigation policies, irrelevant of the geographical and political scales where these are developed (Claus et al. 2015). Finally, the capability approach focuses on people's own evaluations of well-being. Thereby, it offers flexibility regarding a local variability in the impacts, experiences of and responses to environmental or agrarian change (Walker 2009, Schlosberg 2012). As some people may choose to live in risky environments such as fertile floodplains, the capability approach retains flexibility in how people secure their functionings. It may thus also help to contrast local with global perceptions of justice.

3. Empirical setting

Field research for this thesis was conducted in a key region of agrarian change in Indonesia, the lowlands of Jambi province, Sumatra. In the following chapter, I will briefly introduce this empirical setting. First, I will outline the general characteristics of the recent agrarian change in Indonesia. I will then, second, work out the social and environmental transformation processes that have come along with this change. Site-specific land use history, socio-economic characteristics and physiographic conditions are described in more detail in chapters II-VI.

3.1. The rise of the plantation business in Indonesia

As many other countries in the Global South, Indonesia has experienced profound changes in its agrarian economy in recent years. In particular, from the 1980s onwards it has increasingly focused on the production of global commodities such as rubber, palm oil and pulpwood (Barr 2006).

The first plantation systems for global production were already established during Dutch colonial times in the 17th century (Locher-Scholten 2003). These included the cultivation of spices, such as nutmeg, cinnamon and pepper and, since the beginning of the 20th century, also of the exotic rubber species *Hevea brasiliensis* (Beckert 2016). Yet, in many parts of the country, such plantation systems were rather extensively managed and only covered smaller areas. In southern Sumatra, in Jambi province, for example, forest areas (including agroforestry systems) still covered around 70% of the province's area until 1985 (Murdiyarso et al. 1995). It was exactly at that time that in many areas, including Jambi, land use began to change more rapidly. Back then, President Suharto (1967-1998) and his military regime pursued a paradigm of economic development that mainly rested on the exploitation of natural resources in Indonesia's Outer Islands (Barr 2006). In consequence, large-scale logging and export-oriented plantation concessions were granted on islands such as Sumatra or Kalimantan (ibid.). In addition, President Suharto resettled millions of people from densely populated Java and Bali to these more sparsely populated islands (Fearnside 1997, Barr 2006). Under the so-called transmigration program (*transmigrasi*), the resettled families received around 2.25 ha each (Fearnside 1997). With the support of private or government-owned companies, this land was then to be developed as rubber or oil palm plantation. It is estimated that to Jambi province alone, almost 300,000 people were resettled under this program between 1967 to 1995 (Miyamoto 2006).

A rapid expansion of the plantation systems also continued after the fall of Suharto's military regime. During this period of legal decentralization, vague formulations regarding newly attributed authority led to overlapping and competing authority over forest resources (Moeliono and Dermawan 2006). In consequence, district and provincial authorities started granting innumerous logging and plantation concessions on their own (Moeliono and Dermawan 2006, Bullinger and Haug 2012). These "emerging excesses" (Bullinger and Haug 2012: 246) at the local level were partly halted through legal reforms recentralizing authority over Indonesia's forest resources. Despite this recentralization, plantation expansion in Indonesia continued further. Inter alia, it was pushed through the additional granting of oil palm and pulpwood concessions at national level but also due to regional development programs, such as district-to-district transmigration projects (Barr et al. 2006, Wakker 2014, Hein et al. 2018).

Well established value chains, rising global market demand and profitable income opportunities also contributed to the engagement of many independent[9] smallholders in the plantation business (McCarthy 2010, Li 2014, Clough et al. 2016, Schaffartzik et al. 2016). Gradually, smallholder farmers started converting their rubber agroforestry systems or clearing additional forest areas (Feintrenie et al. 2010, Clough et al. 2016). First, mainly into more intensively managed rubber plantations and, from the mid-1990s onwards, preferably into oil palm plantations (Feintrenie et al. 2010, Schwarze et al. 2015, Euler et al 2016). Such spontaneous and smaller-scaled plantation development not only included local farm households. In particular the development of oil palm plantations was also strongly pushed by newly emerging actor groups. These included spontaneous migrants and absentee investors who, over time, became important groups engaging in Indonesia's plantation business (Varkkey 2013, Steinebach 2017, Purnomo et al. 2017).

These developments have turned the plantation business into an important sector contributing to the Indonesian national economy. In 2019, the export value of the total Indonesian plantation produce (excluding timber and pulpwood) was estimated at 25 billion USD (Direktorat Jenderal Perkebunan 2019: 13). Palm oil had by far the largest share therein. Its 2018 export value was estimated at 23 billion USD alone (Purnomo et al. 2020). In total, palm oil thereby contributed to 17% of Indonesia's agricultural gross domestic product in 2014 (MoA 2015, cit. in Purnomo et al. 2020). According to government data, oil palm plantations also covered the largest part of the country's plantation area: in 2019, 14.7 million ha land were planted with oil palms. These were followed by rubber plantations, which, however, only covered 3,7 million ha (Direktorat Jenderal Perkebunan 2019: 15). In the same year, the national government estimated that 7.3 million people were directly employed in the oil palm business, and more than 4.6 million smallholders were managing oil palm plantations themselves (Direktorat Jenderal Perkebunan 2019: 13). Concrete numbers regarding the importance of timber and pulpwood plantations are more difficult to obtain. This is due to the complex system of forest governance in Indonesia (cf. Sahide and Giessen 2015) as well as due to the joint reporting of wood harvested in logging and timber plantation concessions (e.g. KLHK 2019). Trunk and processed wood from both concession types was estimated at an export value of more than 12 billion USD in 2019 (KLHK 2019: ix). Regionally, the largest share of the plantation produce was harvested in Sumatra: around 70% of the national oil palm produce and 62% of the national trunk wood were harvested there during the past years (Direktorat Jenderal Perkebunan 2016: 9, BPS Indonesia 2019: 13). In Sumatra, the provinces with the largest plantation extent are North Sumatra, Riau, South Sumatra as well as the study site of this thesis, Jambi province (Direktorat Jenderal Perkebunan 2019, KLHK 2019: 66).

3.2. Transformations in the biophysical environment

The development of both small- and large-scale plantation systems has led to an extremely rapid land use conversion on islands such as Sumatra and Kalimantan, in particular in lowland and peatland areas (Miettinen et al. 2012, Margono et al. 2014, Austin et al. 2019). There, the establishment of rubber, oil palm and pulpwood plantations mainly occurred at the expense of forest areas and extensively

[9] Independent here refers to those smallholder farmers not involved in contract-farming schemes, such as former transmigrants.

managed rubber agro-forestry systems (Feintrenie and Levang 2009, Margono et al. 2014, Miettinen et al. 2016, Austin et al. 2019). On the island of Sumatra, this plantation expansion contributed to the conversion of 7,54 million ha of primary forest between 1990 and 2010 (Margono et al. 2012, Austin et al. 2019). And in Jambi province, the (agro)forest area decreased from 70% to only around 30% of the province's area from 1985 to 2013 (Murdiyarso 1995, Melati 2017). Today, primary forests in Jambi province are only to be found in Jambi's highlands as well as individual national parks (Margono et al. 2012) (see Fig. 1, p. 24). Government estimates about the extent of the province's plantation cover vary hugely. While national reports estimate the share of oil palm plantations to be the largest in Jambi province, provincial reports estimate rubber and oil palm plantations to cover more similar amounts of land (BPS Indonesia 2020, BPS Jambi 2020). Public data on timber and pulpwood plantations is not available (but cf. Tempo.com 2013). While pulpwood is dominantly grown in industrial large-scale timber concessions, rubber plantations are dominated by smallholder cultivations and oil palm plantations are planted by both private and state-owned companies, as well as by smallholder farmers.

Such large-scale forest conversion has, together with an agricultural specialization towards intensively managed monocultures, decreased multiple ecosystem functions in the affected areas (Clough et al. 2016, Dislich et al. 2016, Drescher et al. 2016, Klasen et al. 2016). Among those changes debated most heatedly at the global level, are the loss of tropical biodiversity and the emission of greenhouse gases (e.g. van der Werf 2015, Greenpeace International 2019, 2020, Jong 2019b). Forest conversion in Indonesia was found to contribute to a general loss of species diversity, density and biomass (Barnes et al. 2014, Clough et al 2016). It has also led to the large-scale habitat destruction of flagships species such as the Sumatran tiger or the orangutan (Robertson and van Schaik 2001, Wich et al. 2012, Smith et al. 2018, Poor et al. 2019). In addition, substantial amounts of greenhouse gas emissions caused by deforestation, peatland drainage as well as peat and forest fires were found to contribute substantially to global climate change (Koh and Ghazoul 2008, Abood et al. 2014, Miettinen et al. 2017, Meijide et al. 2020, Wijedasa et al. 2017). Equally important, yet mainly discussed at the local level are changes in soil properties and microclimate. Forest conversion to oil palm and rubber plantations was estimated to have contributed to more than 30 cm of topsoil erosion, thus decreasing soil organic carbon and soil fertility (Comte et al. 2013, Guillaume et al. 2015). It was further shown that plantation development contributes to significant increases in local temperatures. Forests were shown to be up to 2.3 °C cooler than oil palm and rubber monoculture plantations (Meijide et al 2018).

Studies regarding the ecohydrological consequences of the large-scale forest and land use conversion are rather scarce. Most of them only provide fragmented and at times controversial insights into the ecohydrological consequences of plantation expansion (cf. also Comte et al. 2012). On the one hand, Yusop et al. (2007), Banabas et al. (2008) and Adnan and Atkinson (2011), for example, found little indications that oil palm and rubber plantations alter an ecosystem's ecohydrological functioning substantially. On the other hand, studies by Sumarga et al. (2016) and Tan-Soo et al. (2016) provided evidence for an increasing occurrence of flood events in oil palm dominated areas. Their findings are in line with two social science studies that found villagers reporting about an increase in flash floods following the establishment of large-scale oil palm plantations (Obidzinski et al. 2012, Larsen et al. 2014). In both studies, villagers were further complaining about lowering water tables during the dry season as consequence of plantation development. Such decrease in dry season water tables was equally observed in a village in Jambi province (Merten 2014). The villagers there largely attributed this change to high water consumption rates by oil palms (ibid.). Natural science studies supporting such studies, however, are lacking so far.

3.3. Transformations in the political economy

Besides such changing biophysical conditions, the widespread establishment of export-oriented plantation systems has also come along with significant changes in local political economies. It has widely been documented that the plantation business has contributed to an increasing household welfare among smallholder farmers involved in the plantation sector (Krishna et al. 2017, Euler et al. 2017, Kubitza et al. 2018, Bou Dib 2018a). Particularly households cultivating oil palm plantations themselves, were found to have increased their household incomes. This has allowed them to increase their household's consumption of food and non-food items and also to increase the level of education of their children (Krishna et al. 2017, Euler et al. 2017, Kubitza et al. 2018). On the downside, it is also well-documented that such increases in income are highly dependent upon the ways how farm households engage in the plantation business (McCarthy 2010, Krishna et al. 2017). Most studies have found that better-off households are those able to profit most from engaging in the plantation business. The rising importance of the production of export crops such as oil palm has thereby also come along with an increase in social inequality (McCarthy 2010, Li et al. 2014, Euler et al. 2017, Bou Dib et al. 2018b).

A major reason behind the unequal opportunity to profit from the plantation business is access to land (Krishna et al. 2017). In Indonesia's Outer Islands such as Sumatra, the agricultural sector still constitutes the main source of household income in rural areas. Hence, access to land and poverty in Indonesia are still strongly linked (McCarthy et al. 2012). The recent agrarian change has come along with a strong increase in competition for land. Thereby, it has enabled an accumulation of land by some, while it has decreased access to land for others. This can be explained by two main developments. First, the granting of large-scale plantation concessions has widely challenged local land rights systems (Steinebach 2008, Pichler 2010, Beckert 2016). Since Dutch colonial times, Indonesia's legal system can be characterized as one of legal pluralism (Kunz 2016). This pluralism has caused overlapping land rights between national legislation and customary rights (ibid.). The granting of plantation and logging concession at national level thus often leads to contestation about competing land claims at the local level (McCarthy and Cramb 2008, Pichler 2010, Steinebach 2013, Beckert 2016, Kunz 2016). In particular under President Suharto, plantation development has been pushed with military force, displacing thousands of people from their land (Barr et al. 2006, Pichler 2010, Beckert 2016). And even today, forceful evictions of local communities claiming customary land rights continue across Indonesia (Steinebach 2013, Jong 2019, Jong 2020).

Second, in addition to competing land claims between national authorities and local communities, competition for land occurs within local communities. The specific characteristics of oil palm management, such as the need for costly agricultural inputs, i.e. fertilizer ad seedlings, make it harder for poorer households to engage profitably in the oil palm business (McCarthy 2010). In consequence, many unsuccessful oil palm adopters end up selling their land due to low plantation productivities and high land prices (ibid.). On the other side of the coin, the low labor requirements of oil palm plantations enable better-off households to cultivate larger areas of land (Feintrenie et al. 2010, Euler et al. 2017). It is exactly such land expansion by better-off households that has been shown to present an important pathway how oil palm adoption contributes to higher living standards among smallholder farmers (Krishna et al. 2017). Finally, competition for land has been spurred through new actor groups such as absentee investors, land brokers or migrant farmers. They present further groups profiting substantially from engaging in the plantation business. Through powerful patronage networks these groups often manage to acquire contested village land, which is granted by local elites and authorities (Steinebach 2017, Purnomo et al. 2017).

4. Methodology

4.1. A qualitative case study approach

Understanding specific socio-natural interactions in all their dynamics, social complexity and larger historical-geographical context is crucial for political ecology analysis (Bridge et al. 2015, McCarthy 2017). For this purpose, political ecology requires in-depth, open-ended, place-based qualitative research that is at least historical in analysis (Bridge et al. 2015, McCarthy 2017). Hence, I choose a qualitative case study approach for this thesis.

The main idea behind qualitative case study research is that research subjects and objects should not be dismantled into individual variables but rather studied holistically, considering the full complexity and integrity of their daily contexts (Flick 2016). It hence focuses on understanding the dynamics present within single settings in as much depth as feasible (Eisenhardt 1989). The advantage of such a research strategy is that it can "'close in' on real-life situations and test views directly in relation to phenomena as they unfold in practice" (Flyvbjerg 2006: 235). It is characterized by its inductive character and its openness towards the research object (Flick 2016). This implies that rather than confirming existing theories it aims to explore social phenomena, uncover new things or develop new theories (Eisenhardt 1989, Herbert 2000, Mayring 2002, Flick 2016). Order, it is often argued, should emerge "*from* the field rather than be imposed *on* the field" (Silverman 1985, cit. in Herbert 2000: 552). A strength and characteristic of qualitative research is its focus on empirical problems as experienced by the research subjects (Mayring 2002). Moreover, it regards subjective, experiential knowledge that is gained through the researcher's lived experience as an asset rather than a hindrance, which allows an in-depth understanding of context, processes as well as of causal linkages (Stake 2008, Flyvbjerg 2011).

Subjectivity is not just present on part of the researcher but ingrained in the central method: interviews, which are – as anything presented by people – always linked to subjective intentions (Mayring 2002). Hence, it is central to the whole research process. Any observable activity can have different meanings to different people and thus needs to be made accessible through description and interpretation (ibid.). As Mishler (1986: 112, cit. in Roulston 2010) pinpoints, the "critical issue is not the determination of one singular and absolute "truth" but the assessment of the relative plausibility of an interpretation when compared with other specific and potentially plausible alternative interpretations." Interpretation, however, is not possible without an extensive previous knowledge about the research object (Mayring 2002). For this reason, the starting point of any analysis needs to constitute a detailed and extensive description of the research object that discloses the previous knowledge and understanding of it (ibid.). This knowledge is then developed further through interpretation, which needs to be triangulated throughout the study period (Mayring 2002, Stake 2008).

4.2. Choosing a research site

As qualitative research focuses on research in individual settings, a careful selection of these sites is necessary. Contrary to random samples in quantitative research, their choice generally builds on theory or information-oriented selection (Eisenhardt 1989, Flyvbjerg 2011). Being embedded in the collaborative research centre "Ecological and Socioeconomic Functions of Tropical Lowland Transformation Systems (Sumatra, Indonesia)" (EFForTS) much of the research that I conducted for this thesis took place in the lowlands of Jambi province. This region was chosen as a research site by the University of Göttingen as it was found to represent one of the regions with "the fastest and most complete conversion of tropical lowland rainforest worldwide" (Georg-August Universität Göttingen 2011: 1). In addition, I also conducted research in Jambi's coastal peatlands as tropical peat swamp forests experience an even faster and more recent conversion than Jambi's lowland rainforests (Miettinen et al. 2016). Building on these two research regions, the thesis hence builds on so-called "multi-sited" fieldwork (Marcus 1995). This does not simply imply conducting geographically different case studies, but aims at following connections between distinctive discourses across sites as well as its ability to posit relationships between different social groups and environments (Marcus 1995).

Different techniques of identifying the research sites in multi-sited fieldwork exist. As suggested by Marcus (1995: 106), I decided to "follow the thing", namely water. I hence choose two sub-districts for research where access to water and protection from water-related risks strongly shape land, people, culture and economy. The sub-district Air Hitam is located in Jambi's inner lowlands and was selected based on its importance as main research site within the EFForTS collaborative research centre (Faust et al. 2013) as well as based on information about the area gained during a scoping field visit in 2015. The sub-district Mendahara Ulu is located in Jambi's coastal peatlands and was chose following a recommendation by a research colleague and a two-day scoping visit to the area in 2017. Both sub-districts overlap partly with small watersheds of the eponymous Air Hitam and Mendahara River. In each sub-district, three to four villages were chosen along an upstream-downstream continuum. While water importantly shapes both regions, both sub-districts differ widely in physiography, land use, history and social characteristics. Choosing "maximum-variation" or "polar types" of cases may constitute an adequate choice of cases to obtain information about the significance of various circumstances for case process and outcome (Eisenhardt 1989: 537, Flyvbjerg 2011: 307).

Early settlements in the inner lowlands centered along the large lowland rivers as these constituted the main transport ways (Locher-Scholten 2004: 36). Their strong seasonal fluctuations shaped not only land use, but also housing social activities and culture (see in more depth chapter IV). Agricultural use mainly built on seasonal food crop cultivation of floodplains and extensively managed rubber agroforests further inland (Scholz 1988: 163ff). The main ethnic group inhabiting these lands is Malay people. Despite being located in the wet tropics, access to water is not a given. Between June and September when evapotranspiration exceeds precipitation, the region is characterized by a biological dry season (Merten 2014). During this season, drying wells may cause the need to access surface waters as a source of water supply.

The coastal peatlands are watery lands. The area was only sparsely inhabited until the turn of the 20th century (Claridge et al. 1994) and today a mix of Bugis (South-Sulawesi), Banjar (South-Kalimantan) and Javanese ethnic groups inhabit the area. The need to balance between too much and two little water has been the crucial precondition for building up livelihoods there (see chapter IV). While the drainage of peat soils poses the risk of fire during dry season, flooding impedes any agricultural activity during rainy season. Access to drinking water is generally difficult. Well water in peatlands often is either too acid for daily usage or even turns brackish during dry season due to salt-water intrusion. Rainwater collection has thus always constituted an important source of local water supply.

Studying these two areas in isolation would certainly not do justice to the regional heterogeneity of Jambi province. Hence, data presented in this thesis is also based on research conducted in other parts of Jambi. This includes the village of Bungku, the study site for my Master thesis, the village Seponjen, where a Master student conducted her fieldwork, and several other communities that were visited during 1-2 day trips during different field stays in Jambi province. These included villages in the neighborhood of Bungku, further inland (district Bungo), as well as in Jambi's southern coastal peatlands (district Muaro Jambi) (see Fig. 1).

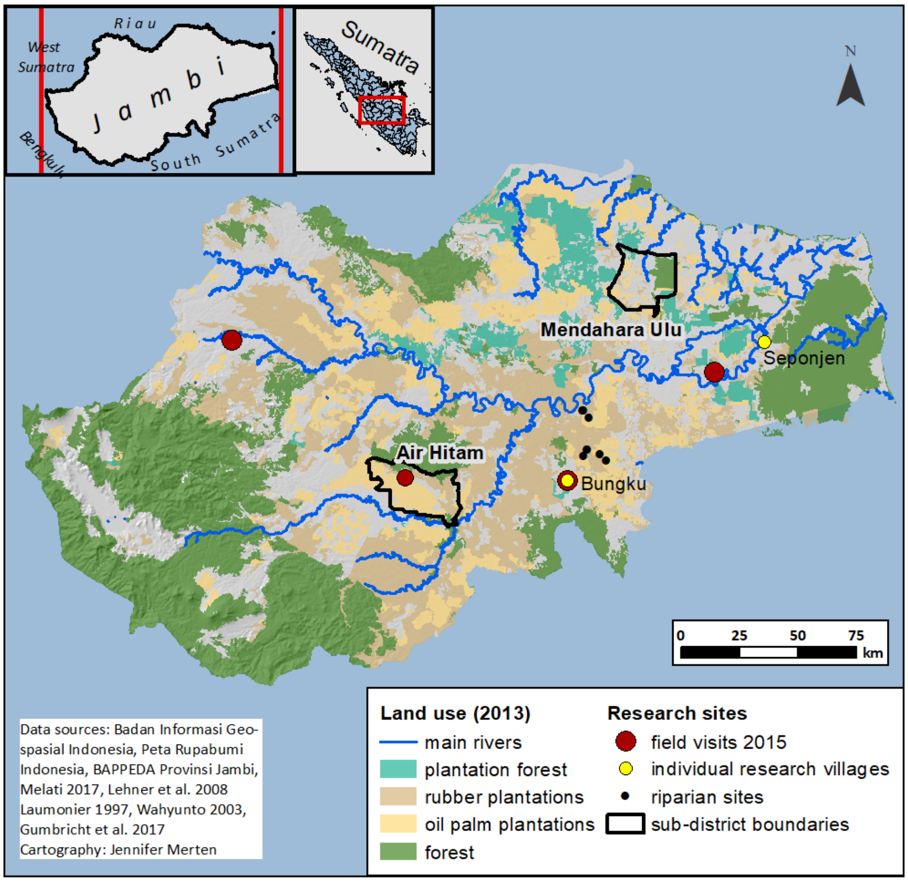

Fig. 1: Overview of study region and research sites.

In Qualitative Case research, generalizability needs to be justified carefully due to its context-bond nature (Mayring 2002). Together with the open research design, it requires a careful retracing of the individual steps of the study to ground careful generalizations (ibid.). Hence, in the following a detailed overview of my different visits to the field and its specific purposes follows.

4.3. Being in the field – access, field stays, purposes

As laid out above, any process of interpretation that guides qualitative analysis requires an in-depth previous knowledge and understanding of the regions, objects and subjects of study (Mayring 2002).

Following extensive literature research on the study region as well as on water and land use change, extensive field research thus constituted the focus during the first years of my PhD studies. During this time, I spent a total 12 months in Indonesia, including almost 10 months in Jambi province.

My first visit to Jambi province already took place in 2012 when I conducted fieldwork for my Master thesis. Following a two-week one-by-one language course in Yogyakarta, I spent a total of two months in Jambi province; interrogating problems of water scarcity in the village of Bungku (cf. Merten 2014).

My second visit to Jambi province followed in September 2015, just at the time when widespread forest and peat fires blanketed Southeast Asia (see chapter V). At that time, a colleague and I visited Jambi province for a scoping visit. In order to interrogate the wider social relevance and regional heterogeneity of our planned research topics. For this purpose we visited two to three villages each in four different regions of the province that varied in land use, land use history, ethnic and cultural history as much as possible and stayed four to five days in each of the regions. The villages were chosen based on an extensive analysis of pre-existing data collected during a household survey in the province (Gatto et al. 2015, unpublished data) (see Fig. 1). Interviews at that time were mainly conducted with representatives from village governments and farmer groups. They focused on questions regarding land use and village history, current socio-economic, cultural and land use characteristics, existing village organizations as well as general challenges and benefits associated with the recent land use change. Already during this field research, it became apparent that environmental changes related to water were important topics in each of the regions visited. While the specific challenges varied across regions, water scarcity, pollution and flooding were mentioned as challenges for securing local livelihoods and plantation management in all villages visited.

These previous field visits provided me with substantial knowledge about the characteristics of land and people in Jambi province before starting my main field research in 2016. This field research was divided into three different stays with each of them lasting around three months. They took place from May to August 2016, from March to May 2017 and from October to December 2017 and thus enabled me to visit Jambi during very different times of the year. The first field stay focused on researching the sub-district Air Hitam, the second focused on the sub-district Mendahara Ulu and during the third stay, I visited both sub-districts for a second time.

Before entering the field, I took an intensive one-on-one Bahasa Indonesia language course of three and two weeks in the city of Yogyakarta in April 2016 and February/March 2017. These courses were essential in acquiring a rigorous knowledge of the Indonesian language, which helped me to gain trust and intimacy with interview partners, as well as acquiring a better understanding of the meaning and significance of the interview results. At later stages, it enabled me to conduct the large majority of the interviews directly in the Indonesian language.

During all phases of field research, I was accompanied by local female research assistants who were (former) students from Jambi University and were recommended by friends and colleagues in Jambi city. Being accompanied by a student from a local university was key to gaining access to the different research villages and also for conducting successful field research in general. All three research assistants - a different one during each field stay - helped to introduce me to village authorities, get around by motorbike, translate language as well as local customs and behavior, record information gained during interviews as well as discuss findings, inconsistencies and the many open questions I had at the end of each day.

The first two field visits served to gain an in-depth overview of the two research regions. Before commencing field research in the different research villages the assistant and I typically first visited the head of the village to acquire research permission in the selected village. During field research, we then either stayed at the house of the village head or with his/her family. The first days were used to interview village authorities, as well as representatives from village and farmer groups or village elders to get an in-depth overview of the village history and characteristics as well as current socio-economic and environmental challenges. After adjusting to village life we then started choosing our interview partners more independently, relying largely on snowball sampling techniques (Jupp 2006: 281) or selected interview partners purposively, because they lived close to a river or owned plantations prone to flooding for example. Over time, this strategy enabled us to delve deeper into specific research topics, uncover new research themes as well as to broaden our perspectives and data sources with regard to interview and research questions.

My third field visit aimed at rounding off research findings from the previous field visits. This visit helped to fill gaps in data by deepening and crosschecking specific research findings and further allowed me to get some insights into local dynamics and developments of my research topic. The fact that I was well known to the villagers when I re-entered the field and my choice to focus on mainly re-visiting former interview partners proved a big advantage. Interviews during this stay were much less formal and more intimate (Fig. 2, p. 29). As my proficiency in Bahasa Indonesia had largely improved over time, I was able to conduct the interviews largely myself, did not need to rely on rigid guidelines and largely refrained from audio-recording interviews. Thereby, interviews often rather resembled conversations between friends and enabled me to get much better insights into personal opinions and evaluations of the research topics as well as to discuss previous research findings. In addition to re-visiting both study regions, during this third phase of field research I also conducted interviews with households owning oil palm and rubber plantations on riparian sites, which were sampled by natural scientist of the EFForTS project (Georg August Universität 2015). In addition to research in the village, all field visits also aimed to include external perspectives through conducting expert interviews (Flick 2016: 214). Several days spent in the city of Jambi, as well as in (sub-)district capital cities of our study areas were thus used to conduct interviews with representatives from government bodies, academia, civil society organizations, as well as private companies (Fig. 4, p. 29).

During each stay in Jambi province, we travelled back and forth between the villages and Jambi city. These breaks in between repeated phases of field research appeared crucial in structuring field visits. They allowed me to complete and order field memos and interview records, reflect on previous research findings, develop long lists of open questions, adjust interview guidelines and to plan research activities for the upcoming trips to the villages. Similar to travelling back and forth between the village and Jambi city, travelling between Jambi and Germany helped ordering my research activities. Staying in Germany for four to six months between each field trip enabled me to organize and evaluate research data by working out open questions, related interview topics or inconsistencies in research findings as well as to review additional literature in the meantime.

4.4. Research methods

This research follows a "transactional approach" to validity (Cho and Trent 2006: 322). It thus builds on the presupposition that qualitative research can be more credible as long as certain methods and research strategies are employed by which misunderstandings can be adjusted and fixed throughout the research process (ibid.). Such strategies include the triangulation of data through the adoption of different research methods, repeated interview situations as well as "member checking", a process in which collected data is 'played back' to the interview partners to check for their reactions and evaluations (Cho and Trent 2006: 322, see also Berger 2015). Only such a combination of different qualitative research methods can produce such "rich thick descriptions" that are typical for political ecology (Núñez 2015: 460).

Semi-structured and informal interviews as well as participant observation build the main research methods applied in the field. Semi-structured interviews are guided by a set of guideline questions, which can be adapted during interview situations (Bernard 2006: 205). The strength of this type of interview is that it allows for comparison between different interviews but also enables flexibility to react to emerging topics during conversations or to deepen interview topics related to an interviewee's personal background and/or function (ibid.). They are particularly useful for when one only gets one chance to interview a person (ibid.) and thus were also the preferred choice for expert interviews, for example, with government representatives or with the owners of the riparian sampling locations.

Initial interviews during the first and the second field research were guided by a number of pre-defined questioned. Different interview guidelines were used for farm households, representatives of the village government and representatives of specific village groups or organizations. As this research followed an inductive, bottom-up research approach, the interview guidelines comprised a broad range of topics (Appendix 1.a). They mainly covered questions about: household characteristics, important village developments, such as current projects and challenges to village development, practices of land management and challenges therein, perceptions of environmental change, the role and importance of specific village organizations or actor groups, existing land use regulations and spatial heterogeneity in and between villages. Interviews at later stages during field research were rather guided by specific themes and topics than by pre-defined sets of questions. They included topics such as: household and village level impacts of water risks (flooding, water scarcity, fire, water pollution) strategies of coping with and adapting to water risks, peatland management, food crop cultivations, water infrastructure, village society, absentee investors, fire prevention or crop choice. Interviews with the owners of the riparian sampling locations were coordinated with different natural science colleagues. The guideline for these households is attached in the appendix of this thesis (Appendix 1.b).

Informal and unstructured interviews on the contrary do not follow a guideline (Bernard 2006: 203ff). While unstructured interviews may still include formal interview situations, informal interviews include conversations during the course of a day in the field. Situations that are more casual often allow to gain more personal insights into specific topics than formal, recorded interviews as well as to uncover new topics of interest that may have been overlooked previously (ibid.). Yet, due to their informality, they limit the researcher in his or her way of leading and controlling the conversations, which, for example, might suddenly be interrupted by someone else entering the situation (ibid.).

Moreover, some difficulty lies in the fact that informal interviews require the researcher to remember as much as possible from a conversation and thus require a constant jotting of field notes (ibid.). Such informal interviews varied widely in their degree of informality. They included planned visits to villager's plantations, when research purposes were obvious, to completely informal conversation during dinner, social festivities or along the roadside.

Finally, participant observation was used as another research method. Participant observation means, "going out and staying out", experiencing the lives of the people that one is studying (Bernard 2006: 324). Ideally, it means immersing into the field, into a different culture and simply taking part in daily life until people behave as usual when one shows up (Bernard 2006: 324). Such an approach to participant observation would require a lot of time, especially for a white, European researcher in rural Indonesian with villages of several thousands of inhabitants. It is also hardly realizable in multi-sited field research. However, we tried to participate in village life as much as possible and gratefully accepted any invitation we got. Such activities included joining wedding ceremonies, farmer group meetings, joint cooking for fast breaking during the fasting month of Ramadan, boat trips along the Mendahara and the Air Hitam river, visits to interview partners' plantations or other interesting places across the villages as well as taking part in gossip and conversations about the developments of the village. Such kind of participant observation has the advantage that it allows gaining experiential knowledge, knowledge that allows one to recount how it is or it feels like to live in the site of study (Bernard 2006: 322). Moreover, it allows to collect many different kind of data such as photographs, which I collected intensively as they proved to be extremely helpful in memorizing personal impressions as well as sharing experiences, for example during conference presentations.

A small number of group discussions were also organized in both case study regions and proved useful in gaining insights into local discussions and arguments around specific research topics. Organizing such discussions, however, often appeared very time consuming while their success was not always guaranteed, for example, if participants called off the meeting spontaneously. Moreover, guiding a conversation between a group of up to eight smallholder farmers in Indonesian language presented a particular, though enjoyable, challenge in itself.

In total, I conducted 229 interviews during my different field visits. These included 46 expert interviews and 183 interviews at the village level (Fig. 2 and Fig. 4). The latter comprised 98 formal interviews (incl. group discussions) and 85 informal interview situations (incl. field trips). While first field visits were dominated by formal interview situations, during later field visits more informal interview situations presented the majority of the interviews conducted (Fig. 2) In total 104 of the formal interviews were audio-recorded (plus group discussions). Most of the recorded interview lasted between 45 min and 1 h 15 min (n= 58). Only six interviews were shorter than 45 min and 36 interviews lasted longer than 1 h 15 min (Fig. 3).

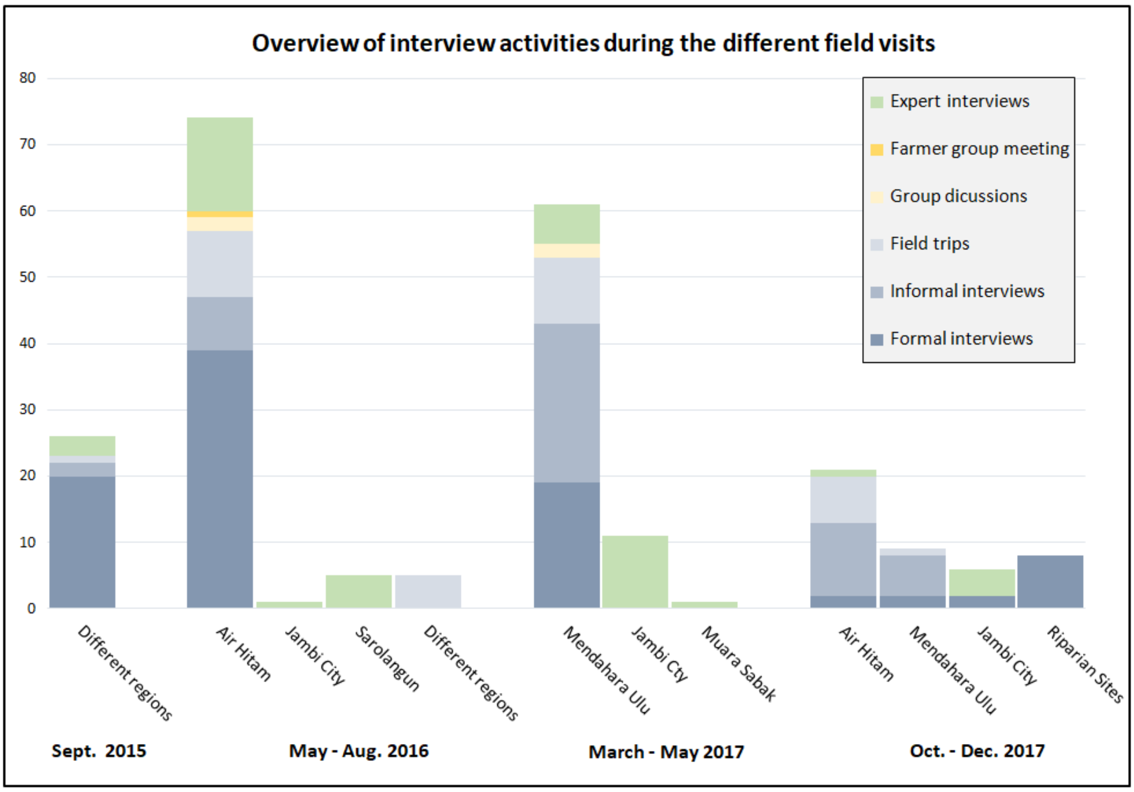

Fig. 2: Overview of interview activities during the different field visits. (Sarolangun and Muara Sekalo are district capital cities).

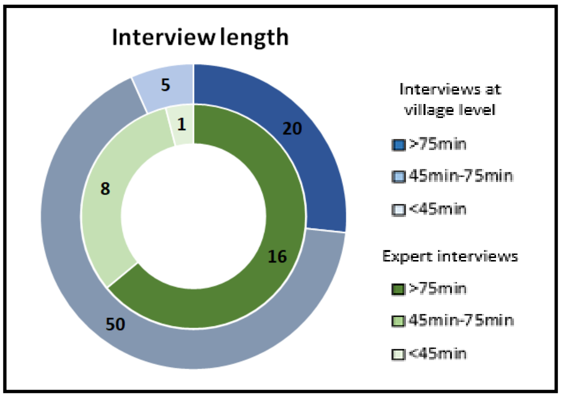

Fig. 3: Average interview length.

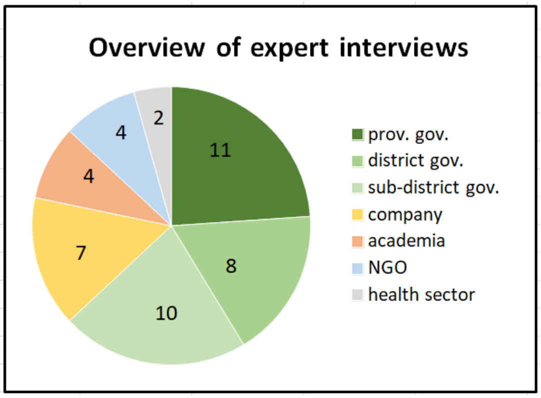

Fig. 4: Overview of expert interviews.

4.5. A word on ethics and positionality

As with any research involving human beings, this research started with several ethical reflections on how to do field research that can establish a relationship that would be valuable for all involved parties. When entering the field, it soon became apparent that several of our interview partners had made previous experience with other researchers in their villages. Not all of these encounters were remembered in a positive way because few of the researchers had spent a longer time in the villages or had explained their research purpose properly.

My assistants and I hence tried to find our own ways and strategies in order to enable more sensitive encounters with our interview partners. Before every interview, we visited our potential respondents to obtain their approval to being interviewed. At this occasion, we shortly introduced ourselves and explained why we were interested in talking to them. The interview partners themselves were then able to choose if, when and where an interview would take place. Before getting started, their formal consent for conducting the interview was obtained. We explained the background and purpose of my research in more detail, assured confidentiality and anonymity of all information provided and made clear that any contribution was voluntary and the interview partners could stop the interview at any time they wanted to. Finally, we asked them for permission to audio-record the interview. After switching off the recorder at the end of each interview, we ensured that there was enough time for more informal conversations. We then encouraged the interview partner to ask questions him or herself about anything of interest related to our personal backgrounds, the research, Germany or else. Moreover, we tried to show our appreciation towards the interview partners by different gestures. We brought small mementos, including a hand-made card to express our gratitude about their participation in my research. We also took a joint photograph after each interview, which we handed out personally when coming back to the village, to enable another informal encounter and gesture of appreciation. Finally, we tried to meet several of our interview partners on several occasions and asked for permission to leave the village (an Indonesian habit to say goodbye) at the end of each field stay.

Despite trying to obtain people's formal consent and being transparent about my research aim, both aspects also had limitations. Explaining the background and purpose of my research before each interview, for example, at times constituted an act of balance between being as open and transparent as possible, yet not revealing too many details, which could influence the research participants' responses. In addition, while research participants were asked for their consent in the case of formal interview situations, informal conversation did not allow for this. Bernard (2006: 211) even acknowledges that any type of informal interviews often involves some kind of deception to keep people from knowing that one is studying them. Openly and repeatedly communicating about me being a researcher and my topics of research as well as being particularly careful regarding confidentiality of information obtained during such situations was my choice of dealing with such situations. However, it could certainly not prevent that I gathered information that was not meant to be shared as research data but still helped me broadening my understanding of issues at stake.

At the beginning of my research, I had committed myself to sharing research findings with villagers during my last field visit. Unfortunately, this was not possible in a formal way due to political concerns in our research project. Moreover, many findings and conclusions were only formulated once field research had finished. Informally discussing some of my initial findings during later field visits was thus the only way to do so. Further, I tried to share concerns and challenges raised by villagers during expert interviews with relevant government representatives. Through collaborating closely with the University of Jambi and the Agricultural University of Bogor, I further had the chance to discuss my research findings (in particular chapter IV) extensively during colloquia in both cities. Additionally, as I had already conducted research in Jambi province for my Master thesis I was able to share research results on water scarcity related to oil palm expansion whenever this topic was brought up by individual interview partners.

Finally yet importantly, qualitative research is a process of interactions (Mayring 2002). Hence, some words on positionality and power relations need to be added. As Temple and Edwards (2002: 6) note, in cross-cultural, cross-language research a 'triple subjectivity', shaped by researcher, assistant and the interview partner influences knowledge production in the field. Being a white, European, unmarried, well-educated woman about 30 years old certainly left its stance on the research findings. In particular, being obviously white had both advantages and disadvantages. On the hand, many people were wondering about who I was and what I was doing in their village making them curious to talking to me. It also proved hugely beneficial to get access to even high-ranking government representatives who gladly took their time for an interview with me. On the other hand, being white also posed several challenges for conducting research at the village level. Wherever I came, I was elevated as a special guest being offered the wedding buffet first or being invited to join lunch with the district governor. This certainly impeded me from truly submerging into the field and made my research assistants often feel uncomfortable. On one occasion, I was even asked to give a small speech when a government representative visited one of the villages and was obviously misusing his visit to promote himself as a candidate for the upcoming election of governor. Not willing to support his private campaign, I immediately rejected this offer, which, however, was certainly extremely impolite towards the village head. Moreover, and in particular when I discussed challenges for village development, interview partners often hoped that I could help them in this regard, by either bringing money or having personal connections to public authorities. Explaining the purpose and benefits of my research thus continued a difficult endeavor throughout the field visits.

Berger (2015) acknowledges that being such an outsider can also be an empowering experience for respondents who are elevated into expert positions. However, this was no easy task. Frequently, my level of education seemed to intimidate interview partners, who considered themselves only "stupid" farmers whose course of study was limited to primary school. It often took a lot of effort convincing them that I was interested in their personal opinions and practical experience rather than expert knowledge. Moreover, while my perspective on local developments might have brought a new and different outsider perspective on the research topic (Berger 2015), it is equally true that understanding many things in the field took me much longer than it would have taken for a local researcher who could have collected a similar amount of data in much shorter time.

Equally, my research assistants strongly influenced my research through their individual backgrounds and personalities. Their different intersectionalities (Whatmore 2002) with interview partners, for example, being (non-)Muslim, being born in the same area, or going to the same university as the respondents' children shaped the level of trust and intimacy with interview partners and their calm or extrovert personalities the atmosphere of conversation. Finally, the assistants and I had to get used to each other's working style, for example, in terms of how much translation was needed and to what kind of detail, how much the interview partners were allowed and encouraged to go off topic before returning to the guideline, or how open a question could be posed to get a good and relevant answer, while not influencing their responses (these and other limitations and constraints of my research are further elaborated in chapter 4.8).

4.6. Data recording, coding and analysis

Data analysis in qualitative research is an ongoing process and frequently overlaps with data collection (Eisenhardt 1989). Conducting qualitative interviews, contrary to, for example, conducting a larger household survey usually implies that the researcher him- or herself is present during all interview situations and is thus constantly exposed to the data collected. Data analysis hence begins with the writing of field notes and memos, the adjustment of research and interview questions, the selection of interview partners and a lot of reflection and brainstorming. To make this possible, a thorough, ongoing documentation of research findings is necessary. Hence, all information obtained during interviews was recorded in written form at the end of each day and personal impressions and thoughts were written down in field memos. All audio-recorded (n= 104) interviews were transcribed in Indonesian language with the help of the research assistants.

Data analysis is often that part of the research process that is described with less detail in qualitative research studies (Eisenhardt 1989). While it is certainly impossible to follow exactly, how researchers derive their conclusions from endless months in the field, hundreds of pages of interview notes and hours of interview recordings, some key features in qualitative analysis were identified by Eisenhardt (1989). First, there is a need for a "within case analysis", which aims at becoming intimately familiar with each case separately before commencing the search for "cross-case patterns" (ibid.: 540). For this purpose, I summarized my research findings from each village and noted down personal reflections on the specific research topics following most of the field visits. In addition, travelling back and forth between the different villages, questioning villagers for regional similarities and differences aided acquiring knowledge about regional heterogeneity and local specificities, such as differences in flooding, access to land or societal structures. Based on this in-depth knowledge about the different villages, overall research themes and relationships between different variables emerged which then helped me shape of different hypotheses (cf. Eisenhardt 1989). The research diary where I wrote down impressions, thoughts and reflections after discussions with supervisors, friends and colleagues, conference presentations, or summer schools visited, supported such hypothesis building during the whole research process.

Moreover, during this step of analysis, coding of research data proved crucial. In order to structure and organize research data, in the follow-up of each field research, interview protocols and field memos were coded with MAXQDA software. As Saldaña (2009: 7f) notes, such coding may serve as a heuristic, an exploratory technique of analysis. Since coding is more than just labeling and helps linking ideas and data, it was crucial for hypotheses building (ibid.). Data was mainly coded for content following Mayring (2000). Code categories were hence formed inductively out of the research material and were then revised, adjusted and reformulated stepwise and in feedback loops (ibid.). Initial categories aimed to grasp basic topics arising during the interviews (e.g. "fishing, "customary law" and "flooding"). These were then subsumed under different general themes (e.g. "land use characteristics", "environmental change", "village level politics") or also refined further in case categories became too large to analyze (Saldaña 2009: 10f).

Having coded all data then helped to pursue a more rigorous analysis and interpretation of research data (Saldaña 2009: 7f). Hypotheses that were built during this phase of analysis, for example, "flooding has increased in frequency and intensity", or "flooding shapes crop choices", were then compared systematically with the evidence from each case (Eisenhardt 1989). In an iterative process each case was used to confirm or disconfirm the emergent relationships and hypotheses and thus to establish internal validity (ibid.). This research stage also led to the restructuring of data, such as the building of new code categories and the consulting of additional data sources. Initially, only interview protocols and field memos were coded systematically. Particularly interesting confirming or disconfirming research data was then analyzed in more depth by consulting the original transcripts in Indonesian language. In some cases, interview data alone could not confirm initial hypotheses. This was, for example, the case for the hypothesis "transnational climate mitigation action strongly shapes local land use regulations in Jambi" (chapter VI). Hence, an additional review of grey literature such as government reports or websites was carried out to confirm this relationship.

4.7. Interdisciplinary thinking and collaborations

As laid out in the conceptual framework to this thesis, studying the socio-natural production of environmental risks clearly requires research that transgresses traditional disciplinary boundaries. Hence, this thesis builds on different ways of interdisciplinary thinking and collaborations. In the following, different logics, modes on procedures guiding my interdisciplinary work will be described.

Reasoning for why interdisciplinary research is considered necessary can be guided by different logics, for example logics of accountability or logics of ontology (Barry and Born 2013). The research at hand builds on both. It builds on logic of accountability since the immense public concern, together with the multi-dimensionality of environmental risks, requires research that is able to analyze both social and environmental processes in the production of risk. In addition, this research also builds upon two different logics of ontology that will be described in the following.

First, chapter IV in this thesis ("From rising water to floods: Disentangling the production of flooding as a hazard in Sumatra, Indonesia") can be categorized as a type of interdisciplinary research that according to Barry and Born (2013: 19) aims at the generation of "hybrid or relational objects". Such research is typically grounded in a critique of the society-nature dualism (e.g. Castree 2005, Latour 1993). It thus engenders interdisciplinary thinking and practices as it cuts across the boundaries between the natural and social sciences (Barry and Born 2013). During this PhD project, I have consistently tried to challenge my former perspective on flooding as an external environmental process. By engaging extensively with relational approaches to natural resources and water in particular (e.g. Swyngedouw 2004, Linton 2010, Jones et al. 2014), I have tried to understand both the social qualities and biophysical dynamics of flooding in Jambi. For this purpose, and common for this kind of interdisciplinary thinking (Barry and Born 2013), I have further tried to internalize the fact that any conceptualization of an environmental problem actively shapes and is shaped by the environmental problem itself (Latour 1993). In chapter IV, I use this insight to contest the predominant and immediate categorization of flooding as a hazard in much risk research (e.g. Wisner et al. 2003, Smith 2013). I exemplify how environmental events such as a river overflowing its banks only turn into hazards through the joint effect of human perception, discourse and modification. Environmental hazards, such as flooding, I argue, constitute socio-natural hybrids and need to be studied as such. Chapter IV thereby builds on what Barry and Born (2013) consider an "agonistic-antagonistic mode" of interdisciplinary research. I comprises research that stems from "a commitment or desire to contest or transcend the given epistemological and/or ontological assumptions of specific historical disciplines" (ibid.: 12).

Second, chapter III in this thesis ("Flooding and land use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry") can be categorized as interdisciplinary research that aims at the integration of different knowledge areas, including non-scientific ones (Barry and Born 2013). Building on a critical realist philosophy of science (see chapter I: 2.2.1), chapter III builds upon the ontological logic that empirical phenomena are causally non-reducible (Nastar et al. 2018). Following this logic, any analysis of environmental risk necessitates interdisciplinary knowledge and methodological pluralism[10] in order to make conceptual links about the multiplicity of causal processes (ibid.). It thus builds on an "integrative-synthesis mode" of interdisciplinarity, which understands interdisciplinary practices as achieved through a synthesis of different knowledge areas[11] (Barry and Born 2013: 12). Such synthesis can be approached through the process of integration or negotiation (ibid.) Being embedded in the interdisciplinary collaborative research centre EFForTS enabled me to discuss my research findings with colleagues across different disciplines on several occasions. These discussions soon revealed the lack of scientific measurements regarding specific empirical societal problems, for example villager's observations of changing water flows. Together with different colleagues, I hence decided to explore the potential of integrating local ecological knowledge, captured through qualitative interviews, with natural science measurements in the study of these problems. Expectations of what such integration between different areas of knowledge should achieve differ widely. Traditional perspectives often expect such interdisciplinary endeavors to achieve integration by a "higher-level concept" (Thorén and Persson 2013: 338). Others, however, acknowledge that a theoretical integration of very distant disciplines – such as qualitative social science and quantitative natural science – is unlikely due to incompatible epistemologies and ontologies (Olsson and Jerneck 2013, Thorén and Persson 2013). In particular in a single PhD project, a different and more realistic aim of an interdisciplinary collaboration may hence be to achieve practical integration (Thorén and Persson 2013). Such practical integration is often pursued through "problem-feeding", in which a problem encountered in one discipline is moved to another discipline (ibid.). Starting with the villagers' observations of changing water flows, my colleagues and me thus moved this problem across different natural science disciplines to find explanations for these changes.

In the way we organized our collaboration we followed Danermark's (2019) advice on how to structure an interdisciplinary research process. Danermark identified five important steps in a research process that builds on critical realism. In an initial planning phase, me and another researcher who shared the lead over the project, decomposed the observed phenomena, flooding, into the structures and

[10] Methodological pluralism argues that there are ontological reasons to use different methods to understand structures and mechanisms across different knowledge areas (Danermark 2019).

[11] Critical realist theory here rather refers to different "levels" than to "areas of knowledge". In the social realm such levels could, for example, include the socio-material level, the level of social structure or the level of the person (Bhaskar 2010, Nastar et al. 2018). Following the suggestion by Danermark (2019), however, I prefer to use the term "area of knowledge", which is less imprecise than the term "discipline" but easier to understand than the term "level".

mechanisms that could affect, reinforce or weaken this phenomena. For this purpose, we built upon a literature review of previous research and in-depth knowledge from the research sites. We identified an alteration of soil properties, climatic change and land use conversion as potential mechanisms contributing to an increase of flooding in Jambi province. At a later state of the research, we added different land use practices as another potential mechanism to our research design. We then identified all research project groups and researchers in the EFForTS research centre that oversaw corresponding research methods and data and inquired about their willingness to join our project. Together, we then interrogated existing datasets and measurements, available analytical tools for analysis and the researchers capable of analyzing the necessary data. The second phase in such an interdisciplinary research process is the "disciplinary phase" (Danermark 2019). During this phase, all researchers involved in our collaboration independently analyzed the research data in their specialized knowledge area in an independent manner. Third, a phase of "cross-disciplinary understanding" follows, which, in our case, was strongly mixed with the fourth phase of "transfactual theorizing" that aims at knowledge integration (Danermark 2019).

During numerous group meetings, we started discussing first results of analyses, clarified individual methodologies and research approaches, identified lacking data as well as further needs of analysis. As described in much other literature on interdisciplinary research, this phase of the research process was certainly also a phase of tensions (e.g. Spiller et al. 2015, Anders et al. 2015, Krüger et al. 2016). These included tensions between positivist and non-positivist scientific world views, about the representativeness and validity of disciplinary research findings, about the terminology used and also about the conclusions that could be drawn based on such a diverse set of research data. Finally, building on this methodological pluralism we triangulated findings, discussed complementarities and inconsistencies between local knowledge and scientific measurements. As described elsewhere, a successful collaboration during this research phase requires a number of personal characteristics and contextual factors (cf. Danermark 2019). Without a true open-mindedness among the researchers involved, respectful ways of communication and a passionate as well as patient and enduring attitude towards the research process, our collaboration would have failed for sure. The withdrawal of one researcher from the group during the research process – resulting from a lacking appreciation of qualitative social science methods – exemplified the bumpy road towards knowledge integration. The fifth phase then is the phase of "interdisciplinary understanding", which should lead to an integrated knowledge about the object (Danermark 2019). As Danermark (2019: 379) notes, this should be a phase of a true "melding of disciplines", resulting in unique research outcomes that could not have been produced by the individual disciplines in separate. In our case, this led to the drafting of a joint manuscript for the journal *Ecology & Society* that aimed to achieve a more detailed and complete understanding of the complex causal relations between agrarian change and changing water flows in Jambi province.

Chapter II ("Water scarcity and oil palm expansion: social views and environmental processes") builds on a mode of interdisciplinarity in between those two approaches. Similar to chapter III it builds on an integration of scientific and local knowledge. It thus also presents an "integrative-synthesis mode" of interdisciplinarity (Barry and Born 2013: 12). The ontological reasoning behind chapter II, however, differs from chapter III. Chapter III integrates these different knowledge areas in order to achieve a more complete understanding of the potential causal processes contributing to the production of flooding Jambi. Chapter II, instead, combines these knowledge areas to interrogate both material and discursive dimensions of water scarcity in Jambi.

4.8. Limitations and constraints

As with any research endeavor, this study has a number of limitations and constrains. First, as already mentioned above, there are advantages but also a number of disadvantages to researching people and topics one is an outsider to. Having to learn a new language, getting used to local customs and habits as well as gaining trust from interview partners: it all takes a lot of time and may limit the depth of data obtained. Insider researchers who have a more intimate knowledge of place, history and social developments may often obtain more personal, in-depth, or more specific interview answers or may be able to achieve a richer interpretation of the research topic at hand. Equally, having interviews at least partly translated by a local research assistant may filter meaning, modify discourses, or produce misunderstandings and thereby influence the validity of qualitative research data (Williamson et al. 2011, MacKenzie 2015, Caretta 2015). Although such translation was reduced stepwise during field research, any translation between languages certainly goes along with a loss of detail and precision.

Second, any choice of methods and interview partners is always also determined by practical considerations. Hence, this research mainly builds on household interviews but less on group discussion that could have presented better insights into social interactions or provide more controversial accounts of certain research topics. Two group discussions with women were conducted to hear about their specific concerns regarding environmental change, yet women unfortunately represented the minority of my interview partners. Most local groups, associations and government bodies in Jambi are primarily led by men and snowball sampling starting with one male farmer often resulted in a recommendation of another man. Further, not all of those women whom I encouraged to join the interviews engaged with the same level of confidence and openness as their husbands did. Another group hardly represented are representatives from the plantation sector. Despite multiple inquiries and letters sent to producer associations, official ways of inquiring interviews failed as we received no response or interview appointments were cancelled spontaneously. Regarding this group of interview partners, only two government representatives from the plantation office accepted my interview requests and one oil palm company, where one of my assistants had worked formerly, officially allowed us to interview their staff.

Third, being embedded in a larger research project with well-established local networks between local universities and authorities was hugely beneficial for gaining access to local authorities and acquiring research permits in reasonable time. Yet, in research locations where numerous other researchers had conducted household surveys or had taken soil samples such activities had certainly influenced my interview partners, raising expectations of benefits or forming presuppositions about my research purpose and interview questions. Finally, the interdisciplinary collaboration that I engaged in was a big surplus for my research and my personal experience during this PhD project. However, integrating our multidisciplinary datasets a posteriori implied lacks of data, mismatches in scale, timing and/or locality. Starting interdisciplinary collaborations already with a joint research proposal would have certainly enabled a much more robust way of data integration.

5. Structure of the thesis

The core of this thesis comprises five articles and manuscripts that have been published in or are planned for submission to different international peer-reviewed scientific journals. Each of them provides insights into different parts of the overarching research objectives and questions guiding this thesis. All articles are concerned with specific empirical problems encountered during the extensive field research in Jambi province. Conceptual frameworks and analytical lenses were then chosen individually to best expound and explain the empirical phenomenon or problem encountered in the field. In the following, I will introduce the purpose of each of the articles and outline their relation to the overall research objectives and questions.

The thesis consists of two main parts. The first part, chapters II-IV, focuses on investigating the production of new water risks in Jambi province. These chapters build on different conceptual and methodological approaches that enable a more integrated analysis of risk production. Each of them focuses on different aspects of the hydro-social relations in Jambi and analyzes their specific contribution to the production of risk.

The second part of the thesis, chapters V-VI, draws attention to different risk mitigation policies and their impacts on local communities. Geographically, this part focuses on Jambi's coastal peatlands. As the conversion and protection of tropical peatlands has turned into a topic of great international interest, risk mitigation action there appeared to be of great social and political relevance.

Chapter II: Water scarcity and oil palm expansion: social views and environmental processes

The aim of this first chapter is to understand the production of the risk of water scarcity in Jambi province. It presents a combined analysis of biophysical and political processes that help explain emerging contestations about water scarcity in the village of Bungku. For this purpose, the chapter uses data from my Master thesis (Merten 2014) and integrates these with natural science measurements and data. Specifically, it analyzes villager's perceptions of decreasing groundwater levels during dry season and confronts these with micro-meteorological, eco-hydrological and pedological measurements conducted in oil palm and rubber plantations as well as in forest reference sites. Conceptually, the article uses the framework of the hydrosocial cycle. It helps explain local divergence in villager's environmental perceptions and to explore the wider social and political implications of the ongoing agrarian transformation processes in Jambi province.

I share the first authorship for this article with Alexander Röll from the department Tropical Silviculture and Forest Ecology at Göttingen University. We further involved numerous co-authors from Göttingen University, the Agricultural University Bogor (IPB) and the Center for Climate change and Air Quality in Jakarta. The article was published in the Journal *Ecology & Society* in April 2016.

Chapter III: Flooding and land-use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry

Similar to chapter II, this chapter builds on an integrated analysis of qualitative social science and quantitative natural science research data. In contrast to chapter II, it interrogates the production of flood risk. Conceptually, this chapter adopts a critical realist approach to the study of environmental risk. Critical realism posits that a combination of different knowledge sources is necessary to achieve a thorough understanding of environmental phenomena such as risk. The reasons for this is that critical realism considers all knowledge to be partial, fallible and socially constructed. Building on this premise, the chapter combines different scientific and non-scientific knowledge sources to interrogate the causal processes and linkages between land use change and flooding in the Tembesi watershed in Jambi province. It combines qualitative interview data on local ecological knowledge with river discharge measurements, precipitation data, land use mapping and pedological measurements of soil hydraulic properties. In an outlook, it discusses how such an integration of knowledge helps to provide for a more complete and socially sensitive understanding of the production of flood risk in Jambi province, and also beyond.

I hold the first authorship of this article. In addition, numerous colleagues from Göttingen University, the Agricultural University Bogor (IPB) and the Center for Climate change and Air Quality center in Jakarta were involved as co-authors in the development of this article. It has been published in the Journal *Ecology & Society* in August 2020.

Chapter IV: From rising water to floods: disentangling the production of flooding as a hazard in Sumatra, Indonesia

This chapter adds to chapter III and aims to deepen our understanding of the production of flood risk in Jambi province. It explains why flooding, once considered a normal seasonal phenomenon, today, is largely perceived and represented as a threatening hazard. For this purpose, it takes an entirely different approach to an integrated study of flood risk and conceptualizes flooding as a socio-natural hybrid. This conceptualization allows us to include the discursive and symbolic dimensions of risk and hazard in risk analysis and thereby goes beyond the material changes in flooding described in chapter III. Methodologically, this chapter builds on a historically situated case study approach in two sub-districts in Jambi province. It uses qualitative research data to reconstruct the multiple material and discursive changes in hydrosocial relations in Jambi province over the last three decades. The chapter focuses on interrogating how changes in social relations may explain the production of flood risk in Jambi. However, it also takes into consideration the biophysical processes behind risk production by paying close attention to the specific materialities of flooding. Conceptually, the article brings into conversation literature on relational approaches to water with recent risk literature and works out how these approaches can further our understanding of the production and meaning of environmental risks.

I am the first author of this article. It has been co-authored by my supervisors Heiko Faust and Jonas Østergaard Nielsen from Göttingen and Humboldt University as well as my Indonesian counterparts Rosyani from Jambi University and Endriatmo Soetarto from IPB Bogor. The article was accepted for publication in *Geoforum* in November 2020.

Chapter V: Indonesia's fire crisis 2015: a twofold perturbation on the ground

This chapter introduces the second part of this thesis. It looks at a different environmental risks related to changes in the local water flows, namely the risk of fires in drained peatlands. Building on qualitative case study research from a village in Jambi’s coastal peatlands, the chapter investigates the social impacts of the large-scale peat fires during the extremely dry El Niño year 2015. It critically analyzes policies on the prevention and control of peat and forest fires, which were developed in the aftermath of the fires, and works out the implications of these for smallholder farmers. Conceptually, it builds on a context-oriented approach to vulnerability. It differentiates between material and political dimensions of vulnerability to explain why risk policies have resulted in maladaptive outcomes for the local communities.

The article was mainly elaborated by a Bachelor student, Flora Hartmann. I assisted her in carrying out her field research in Jambi province, joined her in discussing research questions and findings and helped developing this article as the second co-author. The article was published in the Journal *Pacific Geographies* in January 2018.

Chapter VI: Transnational climate mitigation action in tropical peatlands – implications for smallholder farmers in Indonesia

This chapter continues the research endeavor of chapter V but delves even deeper into the analysis of the social impacts of risk mitigation policies in Jambi province. It traces how transnational policy efforts to mitigate environmental risks from peatlands, i.e. fires and carbon emissions, materialize in new policies, projects and land use agreements in Jambi’s coastal peatlands. It uses a capability approach to climate justice to analyze how such transnational climate mitigation action fails to comply with fundamental criteria of justice and analyzes how this impacts local people’s well-being. Methodologically, the chapter builds on insights from qualitative case studies in different villages in Jambi’s coastal peatlands. These are complemented with an extensive review of government reports, Indonesian legislation and grey literature.

I hold the first authorship of this manuscript. It is co-authored by my supervisors Heiko Faust and Jonas Østergaard Nielsen from Göttingen and Humboldt University and my Indonesian counterpart Rosyani from Jambi University. It is planned for submission to *Mitigation and Adaptation Strategies for Global Change*.

CHAPTER II:

Water scarcity and oil palm expansion: social views and environmental processes[12]

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Abstract

Conversions of natural ecosystems, e.g., from rain forests to managed plantations, result in significant changes in the hydrological cycle including periodic water scarcity. In Indonesia, large areas of forest were lost and extensive oil palm plantations were established over the last decades. We conducted a combined social and environmental study in a region of recent land-use change, the Jambi Province on Sumatra. The objective was to derive complementary lines of arguments to provide balanced insights into environmental perceptions and eco-hydrological processes accompanying land-use change. Interviews with villagers highlighted concerns regarding decreasing water levels in wells during dry periods and increasing fluctuations in stream flow between rainy and dry periods. Periodic water scarcity was found to severely impact livelihoods, which increased social polarization. Sap flux measurements on forest trees and oil palms indicate that oil palm plantations use as much water as forests for transpiration. Eddy covariance analyses of evapotranspiration over oil palm point to substantial additional sources of evaporation in oil palm plantations such as the soil and epiphytes. Stream base flow from a catchment dominated by oil palms was lower than from a catchment dominated by rubber plantations; both showed high peaks after rainfall. An estimate of erosion indicated approximately 30 cm of topsoil loss after forest conversion to both oil palm and rubber plantations. Analyses of climatic variables over the last 20 years and of a standardized precipitation evapotranspiration index for the last century suggested that droughts are recurrent in the area, but have not increased in frequency or intensity. Consequently, we assume that conversions of rain forest ecosystems to oil palm plantations lead to a redistribution of precipitated water by runoff, which leads to the reported periodic water scarcity. Our combined social and environmental approach points to significant and thus far neglected eco-hydrological consequences of oil palm expansion.

Key words: eco-hydrology; environmental perception; erosion; evapotranspiration; forest; land-use change; runoff; rural water supply; streamflow; transpiration

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[12] The social science research data in this chapter builds on field research conducted for my Master thesis (Merten 2014).

1. Introduction

When there was still a lot of forest around Bungku even during a drought of two months we still had water in our wells. But now there is no forest anymore, there is oil palm.

Farmer from Bungku, Jambi, Indonesia, June 2013

Large-scale land-use change such as the current oil palm expansion in Indonesia is characterized by the interaction of social, economic, and ecological processes. It is increasingly recognized that such conversions require research that includes both human and environmental dimensions (Bradshaw and Bekoff 2001, Bodin and Tengö 2012, Moore et al. 2014, Ledford 2015). The integration of local knowledge and perceptions, e.g., the above statement by a farmer from Jambi (Sumatra, Indonesia) enables scientific research to directly address local people's concerns (Ostrom 2009, Pahl-Wostl et al. 2010, Scholz et al. 2011, as cited in Binder et al. 2013). Although the need for such problem-driven research has been emphasized in numerous studies, applied environmental research often fails to adequately integrate social analyses (Lele and Kurien 2011, Wandersee et al. 2012, Tàbara and Chabay 2013, Sagie et al. 2013, Reyers et al. 2013, Orenstein and Groner 2014). Thus, we see a need for applied interdisciplinary studies that give credit to the embeddedness of environmental processes in socio-cultural processes by confronting local environmental perceptions with natural science measurements.

Indonesia is currently undergoing large-scale land-use change characterized by declining areas of natural ecosystems and increasing areas of mono-culture plantations, thereby creating substantial changes in the social-ecological system. Particularly oil palm plantations have rapidly expanded in Indonesia over the past decades, from a total of less than one million ha in 1990 to over seven million ha in 2013; today, Indonesia is the global leader in crude palm oil production (FAO 2015). Oil palm often replaces other cash or subsistence crops, e.g., rubber plantations, but has also been identified as a driver of large-scale deforestation (Koh and Wilcove 2008, Carlson et al. 2012). Such large-scale forest conversion toward intensive agricultural systems may cause severe changes in the hydrological cycle (Bruijnzeel 1989, 2004, Krishnaswamy et al. 2013). In our study region, the Jambi province in Sumatra, the expansion of oil palm plantations has made water scarcity an issue in the human perception as, for example, expressed in the introductory quote. Such socio-hydrological consequences and linkages of forest conversion have not yet been adequately studied (Lele 2009).

Available scientific as well as popular studies linking oil palm plantations to the water cycle mainly focus on water quality (e.g., Wakker 2005, Friends of the Earth et al. 2008, Babel et al. 2011, Colchester and Chao 2011, Buschmann et al. 2012, Gharibreza et al. 2013). The few social science studies examining water quantity do not explain the underlying reasons of the observed declines in water availability (e.g., Obidzinski et al. 2012, Larsen et al. 2014). From the natural sciences perspective, water-related studies on oil palm are scarce and often only examine single components of the hydrological cycle (also see Comte et al. 2012, Dislich et al. 2015).

In this study, we aim at integrating social and natural science approaches to analyze the social and eco-hydrological consequences of oil palm expansion. The starting point for our interdisciplinary, problem-oriented research is the environmental perception of changes in the water cycle by residents of Bungku, a village in Jambi. We investigate if and how these perceptions can be explained by empirically derived environmental variables that were measured in the vicinity of the mentioned village. For this purpose, we analyzed micrometeorological, eco-hydrological, and pedological measurements in oil palm plantations, rubber plantations, and forest sites. Unlike oil palm, rubber has been cultivated in Jambi since the first half of the 20th century (Feintrenie and Levang 2009). Rubber plantations today still represent the dominant land-use system in the province, extending over 660,000 ha in 2013 (BPS Jambi 2014). Our approach allows for an assessment of the environmental perceptions and eco-hydrological processes following forest conversion to monoculture plantations. We also analyzed long-term climatic data to evaluate the influence of potential climatic changes in the Jambi region. Our objectives were (1) to asses villagers' perceptions of changes in the local water cycle in an oil palm dominated region, (2) to identify environmental processes leading to changes in the water cycle, (3) to confront the perceived changes with empirically derived environmental data, and thus (4) to derive complementary lines of argument to discuss environmental perceptions in the context of the actual underlying eco-hydrological processes.

2. The hydrosocial cycle and environmental perceptions

The hydrosocial cycle (after Linton and Budds 2014) serves as a framework to analyze water as a product of society-nature interrelations. Although the concept of the hydrological cycle focuses only on the material components of water, the way that water actually flows through landscapes is drastically shaped by human institutions, practices, and discourses (Linton and Budds 2014). Water can therefore be considered something inherently political, because the control over water produces certain types of social power relations and structures (Wittfogel 1957). The hydrosocial cycle builds upon the notion of water as a "hybrid" object (Latour 1993), i.e., one that simultaneously possesses a social and a natural dimension that are engaged dialectically as both product and agent of socio-natural change (Swyngedouw 2004). Water is thus considered to have a material energetic dimension, such as the flow of water that can change landscapes and established social orders and that provides the basis for individual or societal claims, as well as a cultural-symbolic dimension formed by symbolic orders, interpretive contexts, and social constructions (Becker et al. 2011). The hydrosocial cycle can thus be defined as a socio-natural process by which water and society interact materially and discursively (Linton and Budds 2014). In order to untangle the social and natural processes coproducing this hybrid nature of water, we combined qualitative social field research with natural science empiric measurements in this study.

From the social science perspective, we approach the hybridity of water through environmental perceptions. Environmental perceptions can be defined as the "reception and processing of information from the environment" (Ittelson 1973:4). This includes both the assessment and the evaluation of information, which implies embedding the environmental context into individual experiences, imaginations, and memories (Schiffman 1982, Bell et al. 2001). As such, the way in which individuals analyze the environment and environmental changes is influenced in particular by environmental knowledge and values, place attachment, interests and motivations, but also by the specific prevailing circumstances such as time or cause of environmental change (Hellbrück and Fischer 2003, Chokor et al. 2004, Brown et al. 2005, Sampaio Sieber et al. 2011, Boelens 2014). Environmental perceptions thus have to be understood as context-related, dynamic, and discursively formed knowledge that is open to negotiation and change (Irwin 2001). Accordingly, both conformity and nonconformity of environmental perceptions vs. measured environmental processes have been reported (e.g., Moser 1984, Poor et al. 2001, Artell et al. 2013, Cottet et al. 2013).

3. Methods

3.1. Study region

Our research is part of EFForTS, an interdisciplinary research project investigating ecological and socioeconomic functions of tropical lowland rainforest transformation systems (http://www.uni-goettingen.de/crc990; Faust et al. 2013, Drescher et al. 2016). The study region of EFForTS is Jambi Province in the eastern lowlands of Sumatra, Indonesia. The field work for this study was carried out in the South of Jambi Province, in and around Bungku village (Fig. 1). Climate in the region is tropical humid (26.5 °C, 2235 mm year^{-1}, based on data from the meteorological station at the airport Sulthan Thaha, Jambi), with a relatively dry season from June to September (monthly precipitation often below 120 mm). Between 1985 and 2007, 1.7 million ha of forest were cleared in the lowland areas (< 150 m elevation) of Jambi province, which corresponds to 71% of the 1985 forest area (Laumonier et al. 2010). Today, mono-culture rubber and oil palm plantations dominate the landscape. Rubber has been cultivated in Jambi since Dutch colonial times (Feintrenie and Levang 2009); oil palm cultivation started in the mid-1980s and expanded to almost 600,000 ha in 2013 (BPS Jambi 2014).

The Bungku village spreads over an area of 600 km^2 and comprises five hamlets. The social scientist case study was conducted in two neighboring hamlets in northern Bungku, Bungku Indah and Johor Baru 1 (see Fig.1). Until the 1980s, Bungku was still dominantly covered by forest areas, extensive rubber agroforests, and shifting cultivation land-use systems. Since then, intensive logging, the expansion of rubber plantations, and the establishment of oil palm plantations, which was promoted particularly since the mid-1990s (Colchester et al. 2011), led to rapid deforestation. Today, natural vegetation can only be found in patches in the Harapan Rainforest, a forest rehabilitation project in the southern area of Bungku (Fig. 1). In 2013, land use in Bungku Indah was characterized by about 60% rubber and 40% oil palm cultivation, with oil palm strongly increasing in recent years (*personal communication* with village head); Johor Baru 1 was predominantly characterized by industrial and smallholder oil palm plantations. The company PT Asiatic Persada holds an oil palm concession of 20,000 ha directly bordering the Johor Baru 1 (Fig. 1). Indigenous land claims inside the concession area have been oppressed since the granting of the concession in 1987. The plantation has ever since been the subject of an ongoing land-use conflict involving numerous national and international actors (for more details see Colchester et al. 2011, Steinebach 2013, Beckert et al. 2014, Hauser-Schäublin and Steinebach 2014).

Through constant in-migration from other parts of Jambi and Indonesia the population of Bungku has grown significantly over the last decades. Although the initial settlement project in the early 1970s only comprised roughly 60 households, the village population in 2015 had grown to 10,798 people (Hauser-Schäublin and Steinebach 2014, BPS Kabupaten Batang Hari 2015). About 10% of today's population are indigenous people, 55% are migrants from Java, 30% are migrants from other parts of Sumatra/Jambi province, and 5% come from other parts of Indonesia (*personal communication* with village head). Public infrastructure in Bungku was generally poor at the time of investigation (June 2013). Roads had a severely degraded asphalt cover and public electricity and water supply did not exist. More well-off households had electricity from diesel generators. Household wells, sometimes shared among neighboring families, represented the main water supply for Bungku villagers. These wells differed significantly in construction type, ranging from nonsecured holes adjacent to small rivers to deeper wells secured with cement. Water from these wells was often pumped to the houses with electric pumps. Bottled water has been for sale in Bungku since 2009. Since then, most households buy bottled water for drinking and often also for cooking. Well water is used for people's personal hygiene and washing dishes and clothes (*personal observations*).

The environmental study plots were located on upland mineral soils; soil type is loam Acrisol (Allen et al. 2015), which is characterized by a clay accumulation horizon at a depth of 20 – 50 cm. Measurements were taken on four plots each in oil palm monocultures (HO1 – HO4), in rubber monocultures (HR1 – HR4), and in forest reference sites (HF1 – HF4, Fig. 1). Each of these 12 plots was 50 m × 50 m in size. The oil palm and rubber plots were located in the vicinity (up to 15 km) of the village of Bungku. Management characteristics as well as agroecological site conditions were typical for smallholder plantations in Bungku (*personal observation*). Plantation ages ranged from 7 to 16 years; the plantations were smallholder properties. The forest plots were located in the Harapan Rainforest, 30 km from Bungku Indah. The Harapan Rainforest was partially severely logged until approximately 2003 and became a conservation and restoration area in 2010. Additional measurements were taken in a 12-year-old large-scale oil palm plantation 25 km from Bungku (PTPN6, Fig. 1). For further details on the study region and the overall study design of the EFForTS project, refer to Faust et al. 2013 and Drescher et al. 2016.

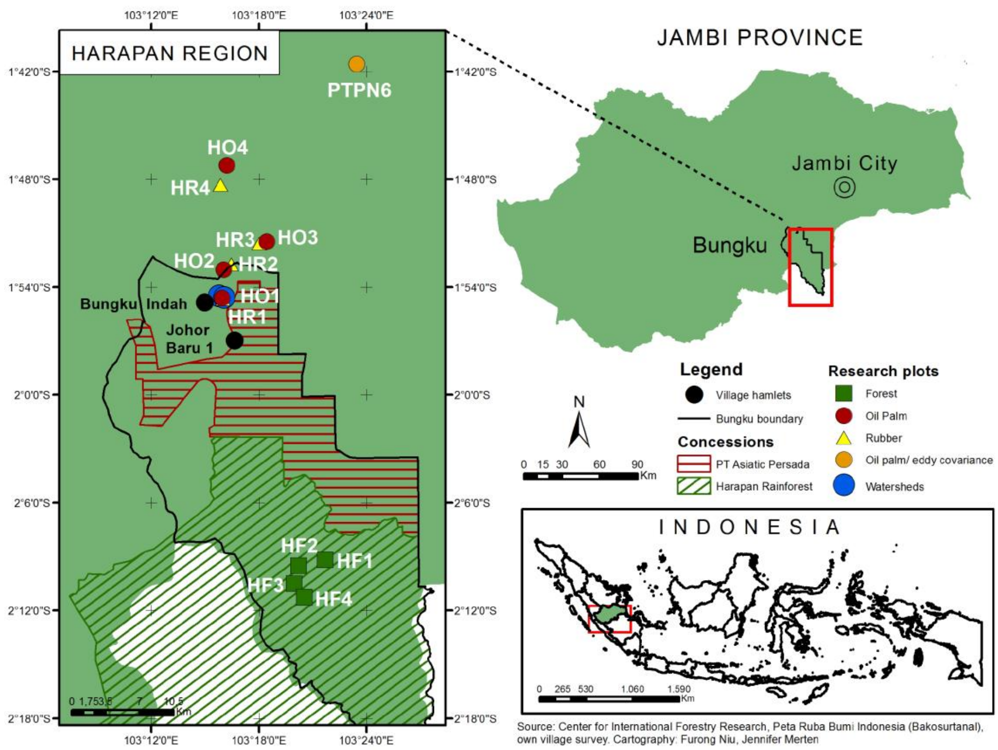

Fig. 1: Location of the study sites in Jambi province, Sumatra, Indonesia.

3.1.1. Social dimension

Based on initial reports about water scarcity in areas surrounding oil palm plantations in Jambi, interest by social and natural scientists led to an inductive social case study. Bungku was chosen because of reports of rapid land-use changes and increasing water scarcity. The case study aimed at investigating villagers' perceptions of major environmental changes, challenges in the local water supply, and processes that potentially cause problems for the water supply.

To investigate these questions we conducted problem-centered, semi-structured household interviews (after Mayring 2002; n = 30) that were triangulated with participatory observation, informal interviews, focus group discussions, and participatory rural appraisal tools, i.e., timeline interviews and resource mapping (after Kumar 2002). Field work in Jambi was conducted during a period of eight weeks from May to July 2013. Respondents were chosen according to the snowball sampling method (Schnell et al. 2013), trying to reflect the social structure of the hamlets. Supplementary information was obtained through nine key informant interviews with representatives of the private sector, civil society organizations, and public authorities at the regional and national level. For further details on interview procedures and data processing refer to Appendix 1.

During the research process it became clear that changes in the local water cycle could not easily be separated from the political discourse about them. We thus chose the hydrosocial cycle as a conceptual framework to cope with these existing ambiguities and to analyze the different dimensions of socio-natural relations. Applying this framework, the social and natural scientists involved in the study jointly discussed if and how the villagers' perceptions from the social case study could be explained by empirical environmental datasets.

3.1.2. Environmental patterns and processes

Land-use change

In the PTPN6 large-scale oil palm plantation (Fig. 1), the eddy covariance technique (Baldocchi 2003) was used to measure evapotranspiration, the three components of the wind vector (METEK USA-1, Elmshorn, Germany), as well as water fluxes (LICOR 7500, Lincoln, USA). We used data from three sunny days during October and November 2014 to minimize day-to-day variability induced by weather.

Transpiration rates, soil erosion, air temperature under the canopy, and soil moisture fluctuations were studied on oil palm, rubber, and forest plots (HO1 – HO4, HR1 – HR4, and HF1 – HF4, Fig. 1). To estimate stand transpiration rates we measured sap flux densities with thermal dissipation probes (Granier 1985, 1996) in these 12 plots as well as at the PTPN6 site. For measurements in oil palm leaf petioles, we used the calibration and sampling scheme as proposed by Niu et al. (2015). The standard equation (Granier 1985) was used for trees in rubber and forest plots. For trees, radial profiles of changes in sap flux density with xylem depth were established. To extrapolate from trees and palms to stand transpiration, inventory data were used (Kotowska et al. 2015). Because measurements were partly not conducted simultaneously, we also averaged the values of three sunny days for the analysis to minimize variability induced by weather. More details on these and all other applied methods can be found in Appendix 1.

On the 12 forest and plantation plots, the soil carbon content in the Ah horizon (down to max 10 cm depth) was measured (Guillaume et al. 2015) and soil erosion was estimated by assessing the soil carbon isotopic composition ($\delta^{13}C$) with depth. The $\delta^{13}C$ profiles in the plantations were compared with the forest reference plots, where erosion was assumed to be zero. This was necessary to estimate the thickness of the surface layer lost by erosion after forest conversion. To assess fluctuations in microclimate (air temperature, air humidity, and soil moisture), weather stations equipped with thermohygrometers (Galltec Mella, Bondorf, Germany) and soil moisture sensors (IMKO Trime-PICO, Ettlingen, Germany) were installed on the 12 study plots.

Within two small catchments encompassing some of the oil palm and rubber plots (HO1 – 4, HR1 – 4, Fig. 1), we recorded streamflow and measured rainfall interception for four months. One catchment (14.2 ha in size) was dominated by 10 – 14-year-old oil palm plantations (covering 90% of the catchment area). The other catchment (4.9 ha) consisted of different rubber stands: 8-year-old (19% of the catchment area) and 30-year-old (56% of the area) mono-culture rubber plantations and jungle rubber (25% of the area), a mix of rubber trees and naturally established dicot tree species. We selected a two-week period (7 to 20 Nov 2013) of the recorded hydrographs encompassing both dry and rainy conditions. Rainfall interception of the oil palm and rubber monocultures in the respective catchments was assessed by measuring throughfall and stemflow, and subtracting them from incident rainfall.

Climate change

For the period from 1991-2011, we analyzed air temperature and rainfall data from the meteorological station located at Airport Sultan Thaha, Jambi, property of the Indonesian meteorological service (BMKG). Our aim was to assess whether there have been climatic changes in Jambi over the last 20 years. Mean, maximum, and minimum temperature as well as rainfall data were separated into their time components to detect trends in these variables over the last years. For an analysis of climatic trends on a greater temporal scale, we calculated the Standardized Precipitation Evapotranspiration Index (SPEI) from the Global SPEI Database (SPEIbase; Vicente-Serrano et al. 2010) for the Bungku region from 1901–2011. The SPEI is a multiscalar drought index that takes into account precipitation and potential evapotranspiration to determine drought conditions; a strong drought is reflected by a large negative value.

4. Results

4.1. Social perspectives on changes in water availability

To structure and analyze the environmental perception of the villagers we first describe people's assessments of environmental changes that they observed during their time in Bungku, and secondly people's personal evaluations of these changes. Finally, we discuss impacts on local water supply as a consequence of a decreasing availability of clean water.

Villagers' assessments of changes in local water resources

Over the last 25 years, the villagers of Bungku observed pronounced changes of local water resources. Among the observations mentioned were a faster depletion of groundwater reservoirs during dry periods, a higher fluctuation of river levels with particularly low levels during dry seasons, and an increased pollution of surface waters (see Table 1). The fast depletion of groundwater levels during dry seasons was of particular importance to the villagers because their water supply was mainly ensured by household wells. Wells that dried up in past decades have also been reported. However, the consensus among interviewed villagers in Bungku was that during dry periods the scarcity of well water has started to occur much faster and more frequently since the early 2000s. They observed that since then, in times of prolonged dry periods, many wells in the village fall dry.

In addition to the fast groundwater depletion, community members reported that streamflow levels decrease much faster during dry seasons than had been the case 10 years ago; several smaller rivers stopped flowing after only a few weeks without rain. Swampy areas are generally numerous along streams and rivers in the research region. However, over the past years, many of them were observed to have started to decrease in extent and depth, or to have dried out completely. During the rainy season, very high river levels with quick declines after rainfall events were observed in recent years.

The interviewed villagers also mentioned alterations in water quality. Water quality was reported to have decreased significantly over the past decades, described as changes in water color from "clean" and "pure" in the past to "turbid" and "muddy" at the time of research. Water quality was said to be particularly bad in times of water scarcity. When a lot of wells in Bungku run dry, many villagers rely on surface water for personal hygiene. This then generates further pollution particularly of shallow or stagnant water bodies.

The challenge in accessing clean water was also recognized by an official document on the village development. "Difficult access to clean water" was ranked among the four most urgent issues for all five village hamlets. An additional factor possibly interconnected to seasonal water scarcity in Bungku was the observation of increasing air temperature. Villagers felt it had become significantly hotter since oil palm plantations started to dominate large parts of the landscape surrounding the village.

Table 1: Representative quotes from the interviews and group discussions† of the social case study. Interviews were conducted in the village of Bungku, Jambi, from May to July 2013.

On the drying of surface and subsurface waters	
"Before when people didn't open much of the forest yet there was still water in the river and it still flowed after one month of drought. But since people opened the forest and plant oil palms the water in the river gets less. It doesn't flow anymore."	Middle-class rubber farmer, Javanese, has lived in Bungku since 1999, 60 years old.
"When there was still a lot of forest around Bungku even during a drought of two months we still had water in our wells. But now there is no forest anymore, there is oil palm."	Owner of a kiosk where bottled water is sold, has lived in Bungku since 1995, Javanese, ~50 years old.
"Before there were not so many oil palms. That's why we still had enough water. Because oil palm needs a lot of water, while rubber can keep the water."	Rich woman, born in Bungku, ~30 years old.
'The negative thing about oil palm is that it is a plant that needs a lot of water. That's why, if we plant oil palm near swamp areas, after some time the swamp will run dry."	Rich oil palm farmer during group discussion, Javanese, ~35 years old.
On the increasing pollution of local water resources	
"Did you observe any changes in the water quality?" "Yes, it changed. A lot! Before the water was not that dark, but now it looks like it contains mud. Before there was not that much mud in the water."	Poor, very old woman selling food at a small stand, has lived in Bungku since 1987.
"After rainfall the water in the well becomes turbid. But after some days without rain the water quality gets better again."	Young, middle-class woman, has lived in Bungku since her childhood, ~30 years old.
"The problem comes from the people themselves. The habit of the people here is that if there is no rain for some weeks then they start to go fishing. But they use toxics. And another reason is that the people who live near a river take a shower and wash their dishes in the river. And sometimes they also throw the garbage in the river."	Nurse, has lived in the district for 15 years, ~30 years old.
"The people now have a problem with the water. The water quality of the river is not good anymore. But they still use it for washing and showering since there is no clean water anymore."	Poor indigenous rubber farmer, head of RT (rukun tetangga, neighbor solidarity unit), 40 years old.
On increasing local temperatures	
"When I came to Bungku in 1991 the temperature was different. There was still a lot of forest and the temperature was not as hot as today."	Very rich woman, has lived in Bungku since 1991, Javanese, owns rubber and oil palm cultivations, 29 years old.
"If we are standing under an oil palm and afterwards under a rubber tree and we compare it, then the temperature feels very hot under the oil palm trees."	Oil palm farmer during group discussion, has lived in Bungku since 1993, Javanese, ~40 years old.

†Translations by J. Merten and I. Kasmudin.

Local evaluations of increasing seasonal water scarcity

The explanations by the villagers for the observed changes in local water supply were manifold but were all directly or indirectly related to the ongoing land-use change in the Bungku region. The explanations given for decreasing groundwater and streamflow levels during dry seasons included particularly the ongoing deforestation and the expansion of oil palm cultivation (see Table 1). Water availability was observed to have decreased notably after oil palms became the dominant element in the landscape. Common stories in the village attributed an allegedly high water use to oil palms, which was believed to cause adjacent swamp areas, rivers, and wells to run dry. Rubber plantations, on the other hand, were believed to rather "conserve" or "store" water in the soil. Some villagers reported that wells they built in oil palm plantations ran dry after only a few weeks without rainfall, while wells inside rubber plantations provided water even during prolonged dry periods. Further explanations for the low streamflow of local rivers brought forward by individual villagers included landscape-shaping activities of oil palm companies, e.g., draining of swamps, channelization of rivers, or inadequate canalization in road construction.

Key informants reported that increasing pollution of surface waters was likely related to the behavior of the villagers themselves (see Table 1). The main issues mentioned by the interviewees were the lack of waste and wastewater management in the village, the use of surface waters for personal hygiene, and the use of poison for fishing. The rapid population growth in the village added to this by causing a constantly increasing volume of waste and wastewater. With respect to oil palm cultivation, individual villagers blamed the lack of environmental management and the absence of buffer zones along rivers for increases in the sediment load of local rivers over the last years. Fertilizer and possibly pesticide leaching were reported to be further sources of pollution in other studies (e.g., Banabas et al. 2008, Comte et al. 2012, Obidzinski et al. 2012, Larsen et al. 2014, Allen et al. 2015), but were only mentioned by few villagers in our study.

The evaluations presented above reflect the general opinion of the respondents in Bungku, including both rubber and oil palm farmers. Some indigenous farmers and long-time residents, however, presented different evaluations of local developments. They emphasized that oil palms per se cause most environmental degradations occurring in the area and are, e.g., also particularly "water-greedy." In contrast to this, individual, more prosperous oil palm farmers, company representatives, and local representatives of policy institutions negated most negative environmental impacts of oil palm expansion, rather stressing the economic benefits.

Impacts of decreasing water availability on local water supply

As a consequence of local water scarcity during prolonged dry seasons, the majority of the interviewed households were forced to access different, more abundant water resources. These were often at a distance of up to 10 kilometers from the village. Only those few households possessing a car could transport an amount of water lasting for a couple of days. Poorer families had to rely on richer neighbors to carry additional water for them. Trucks with water tanks could be ordered to the village, but apart from significant costs this implied possessing major storage facilities, which most households did not have. Thus, many households tried to reduce their water consumption and used bottled water for the most essential uses, i.e., drinking, cooking, washing infants. The sale of bottled water at kiosks in the village was reported to roughly double during dry seasons. Concerning personal hygiene, laundry, and the cleaning of cooking facilities, many people sought any other available source of water in and around the village, commonly of poor water quality, e.g., small swamps and rivers. According to statistics of the community health center, skin diseases and allergies were the second most common diseases (after upper respiratory tract infections) in Bungku at the time of investigation. People suffering skin allergies were generally recommended to use bottled water for showering. The degradation of water quality was also reported to lead to substantial declines in fish stocks, forcing villagers to go fishing at the rather distant larger streams near the Harapan Rainforest or to rely on aquaculture.

4.2. Environmental patterns and processes

Land-use change

Evapotranspiration rates derived from the eddy covariance technique in a 12-year-old oil palm plantation in Jambi (PTPN6) were 4.7 ± 0.1 mm day^{-1} (three sunny days, mean ± SE; Table 2). On the same days (and in the same plantation, PTPN6), transpiration by the oil palms as derived from sap flux measurements was estimated to be 2.5 ± 0.1 mm day^{-1}; the remaining 47% of evapotranspiration are likely the sum of transpiration by other plants, e.g. ground vegetation or trunk epiphytes, and evaporation, e.g., from the soil.

Average transpiration rates of the five oil palm plots (HO1 – 4, PTPN6) on sunny days were 1.8 ± 0.3 mm day^{-1} (three sunny days averaged for each plot; mean ± SE represent spatial variability among the five mentioned oil palm plots), 11% lower than the average of the four forest plots (HF1 – 4, 2.0 ± 0.2 mm day^{-1}). However, such a small difference lies within the uncertainties associated with the used approaches (see, e.g., Niu et al. 2015 for oil palm). The rubber plantations (HR1 – 4, 1.1 ± 0.1 mm day^{-1}) had 85% lower average transpiration rates than forests and 63% lower than oil palm plantations. Additionally, rubber trees (partially) shed their leaves during the dry season, which effectively further reduced transpiration (by up to 70% at the peak of leaf shedding).

In the catchment areas, rainfall interception was 28% of incident rainfall in oil palm plantations, whereas it was 17% in rubber plantations. The observed difference is probably related to the high external trunk water storage capacity of oil palms, which we estimated to be 6 mm in a mature plantation in the oil palm-dominated catchment. Butts of pruned petioles remain on the trunk over several years, forming chambers full of humus, water, and epiphytes.

Streamflow data from the two catchments confirmed differences between oil palm and rubber plantations: baseflow under dry conditions was lower in oil palm plantations (1.8 l s^{-1} per ha catchment) than in rubber plantations (8.2 l s^{-1} ha^{-1}). After intense rainfall events (> 60 mm), recorded streamflow levels were strongly elevated in both catchments (up to 21.2 l s^{-1} ha^{-1} in the oil palm and 36.9 l s^{-1} ha^{-1} in the rubber catchment, respectively; Fig. 2).

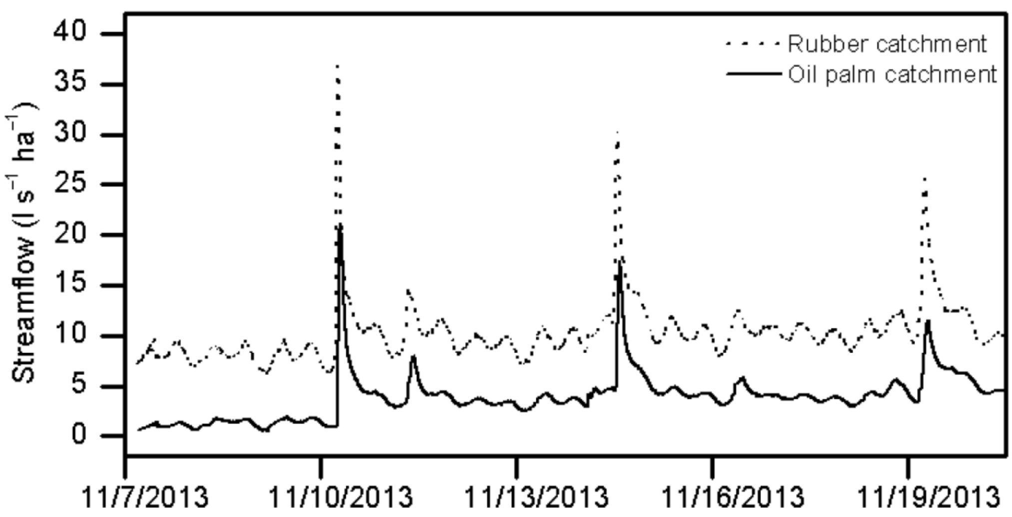

Fig. 2: Streamflow patterns from oil palm dominated and rubber dominated catchments normalized by catchment area. Hydrographs from a two-week period (7 to 20 Nov 2013) encompassing both dry and rainy conditions.

Soil erosion as derived from $\delta^{13}C$ profiles as well as decreases in soil carbon content were similar in oil palm and rubber plots, averaging 35 ± 8 (mean ± SE) cm of top soil loss and amounting to 70% of C content decrease since conversion in oil palm plantations, and 33 ± 10 cm and 62% in rubber plantations (Table 2; Guillaume et al. 2015). On forest plots, erosion was assumed to be zero (see Methods) and the C content in the Ah horizon was 6.8 ± 0.8%.

The analysis of microclimatic conditions inside the plots showed no clear patterns in soil moisture. We think a possible reason is that the variability within the plots was higher than the variability within the land-use systems and thus could not be assessed adequately by only one soil moisture sensor per plot. However, differences were observed in air temperature under the canopy, which was higher in oil palm and rubber than in the forest plots (by 0.4 and 0.5 °C respectively, Table 2) and showed 1.5-fold higher diurnal fluctuations in both plantation types than in the forest.

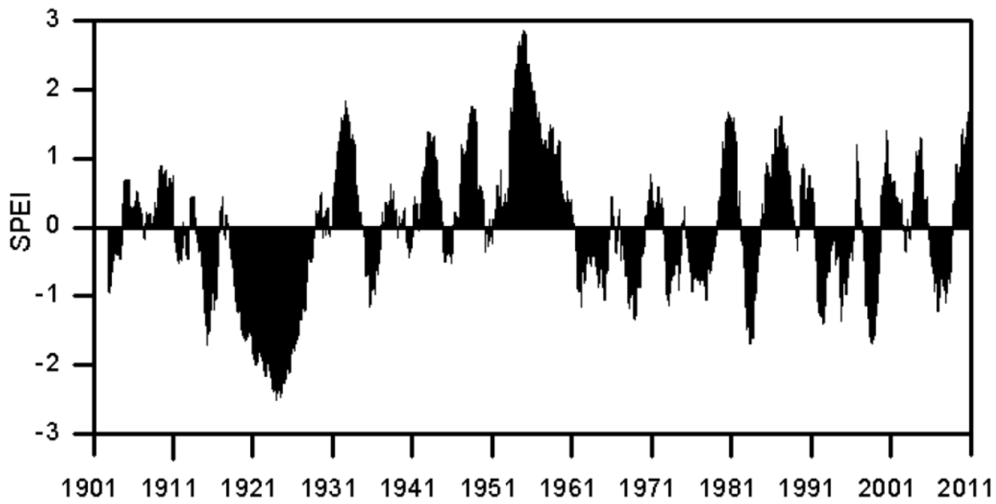

Fig. 3: SPEI index (standardized precipitation evapotranspiration index), a multiscalar drought index, for a 24-month period, from 1901 to 2011 in the Bungku region. Categorization of dryness by SPEI: Near normal (-1 to 1); Moderate dryness (-1.49 to -1); Severe dryness (-1.99 to -1.5); Extreme dryness (less than -2). Same ranges for positive values indicate wetness.

Table 4: Characteristics of the water cycle and connected variables of oil palm plantations, rubber plantations, and forest stands as observed in the lowlands of Jambi, Indonesia (n.d. – not determined).

Variable	Method	Oil palm	Rubber	Forest
Evapotranspiration†	Eddy covariance	4.7 mm d^{-1}	n.d.	n.d.
Transpiration†	Sap flux	1.8 mm d^{-1}	lower	similar
Rainfall interception	Rain gauges	28%	lower	n.d.
Soil carbon content	CN analyzer	2.1%	similar	higher
Stream base flow	Catchments	lower	higher	n.d.
Stream storm flow	Catchments	high peaks	high peaks	n.d.
Soil erosion ‡	d13C profiles	35 cm	similar	n.d.
Air temperature	Thermometers	25°C	similar	lower

†Average of three sunny days.
‡Soil erosion since forest conversion.

Climate change

The analysis of the SPEI indices over the past 100 years suggests that droughts are recurrent in Bungku area (Fig. 3), and that their frequency and intensity has not increased over the last century. The most severe droughts, reflected by a large negative SPEI index value (i.e., -1.5), occurred in 1924, 1983, and 1998; they are associated with strong El Niño Southern Oscillation (ENSO) events.

The evaluation of trends in air temperature and rainfall from 1991 to 2011 shows no significant changes in mean and maximum temperatures. However, the minimum temperature shows an increase of about 1 °C in the period from 2004–2011 ($p < 0.05$), indicating a small decrease in the range of annual temperature variation. Rainfall, for 21 years with complete data series, was 2235 ± 84 mm per year (mean ± SE). Rainfall in Jambi is characterized by a relatively dry period from June to September, when average monthly rainfall is often below 120 mm. In some years such as 1993, 1994, or 2011, this dry season was more pronounced, with at least two consecutive months with monthly precipitation below 40 mm. Other years, e.g., 2005, 2010, were wetter and the dry season was not very pronounced, indicating high variability in the rainfall patterns between years. Based on the evaluated data, we conclude that there were no significant climatic changes in Jambi between1991 and 2011, and probably also not over the last century.

5. Discussion

5.1. Environmental perceptions of changes in the local water cycle

Our study suggests that water availability during dry periods is an increasing problem for the local population in the oil palm-dominated landscape of our study region. The interviewed villagers reported that significant changes in the hydrological cycle have occurred in the study region over the last 25 years. The main concern of the interviewed villagers was the decline of surface and subsurface waters that they attributed to the rapid local land-use change from a landscape mosaic of forest and (agroforest) rubber patches to an increasingly oil palm-dominated land cover. Similar linkages between forest conversion and changes in local water supply have been observed in several studies, e.g., related to the development of payment for ecosystem services schemes (Pattanayak and Kramer 2001, Pattanayak 2004, Asquith et al. 2008, Muños-Piña et al. 2008, Lapeyre et al. 2015). Such schemes are, e.g., introduced to maintain watershed services from forest areas, including stable dry-season streamflow.

The villagers' perception in Bungku was that forest conversion to oil palm plantations impacted local water availability far more negatively than conversion to rubber monoculture plantations. In the opinion of the villagers, oil palm plantations use up a lot of the available water during dry seasons. These statements reflect the evaluation of the great majority of the interviewed villagers, independent of their social background and including dedicated oil palm farmers. This is in line with findings from a household survey in 45 villages in the Jambi province (n = 700; Faust et al. 2013), which showed high awareness of villagers across all social groups of the environmental impacts of oil palm cultivation (M.

Euler, V. Krishna, Z. Fathoni, S. Hermanto, S. Schwarze, and M. Qaim 2012, *unpublished data*). Drying wells and surface waters in the surroundings of oil palm plantations were also reported in studies by Obidzinski et al. (2012), Larsen et al. (2014), and an NGO report by Friends of the Earth et al. (2008).

Two small groups of interviewees, however, propagated different evaluations of the local development. Depending on their social background and their (non)participation in the profitable oil palm business, they either overemphasized or completely neglected negative hydrological impacts by oil palm expansion. This demonstrates that the local discourse on water supply is deeply embedded into a wider discourse on consequences of the regional land-use change. Local water supply is being used as an argument to substantiate personal claims and viewpoints regarding the drastic expansion of monoculture oil palm plantations in the region. The actor groups that vigorously advocated the advantages of oil palm business are among the winners of the ongoing land-use change to agricultural systems. On the other hand, poorer smallholders and indigenous people are confronted with large agricultural investors, which make access to land in the region increasingly unaffordable. Considering the diverse nature of the ongoing land-use conflicts in the area, the described politicization of water scarcity is not surprising. Steinebach (2013), Hein and Faust (2014), and Hein et al. (2015) have extensively described how indigenous people and poor farmers in the area form strategic coalitions and engage in environmental justice discourses to legitimize and strengthen their political claims of access to land and natural resources.

As a consequence of regularly dried up wells, households were forced to access more abundant but often quite distant water resources. The transport of water from these sources heavily depended on access to motorized vehicles. Access to clean water thus was highly dependent on the households' financial situation, i.e., the available capital for purchasing bottled water or ordering larger tanks of water. According to our observations, buying water for drinking and cooking could be afforded by most interviewed households in Bungku, whereas the use of bottled water for showering or other high-water activities would stress household finances substantially. Access to water thus strongly increased social polarizations, further disadvantaging those not participating in the profitable oil palm business.

Cooperation among neighbors in times of need, i.e., times of local water scarcity, generally seemed strong regarding the provision of water. However, recounts of locked wells during the strong El Niño year in 1997 suggest that social cohesion might decline in times of extreme scarcity, which poses risks of social unrest.

In times of scarcity, the increasing use of surface waters for personal hygiene, along with the rapid population growth of past decades, put enormous pressure on local water bodies. Consequently, water from small and highly frequented local water bodies was commonly observed to be of extremely poor quality, which might be a significant cause of diseases, e.g., of the skin. Even the water of larger rivers in Jambi cannot be considered safe because of possible leaching of agrochemicals from surrounding plantations (Comte et al. 2012, Allen et al. 2015) or upstream gold mining activities. For the Muslim majority of the village, this does not only impose problems regarding health, but also regarding religious customs. Clean water is indispensable for the ritual washing before prayers, fast breaking, funerals, and other religious celebrations.

5.2. Environmental processes leading to changes in the water cycle

Evapotranspiration rates derived from eddy covariance measurements for a 12-year-old oil palm plantation (PTPN6) under dry, sunny conditions were similar (4.7 mm day^{-1}) to values reported for lowland rainforests on Borneo (4.2 mm day^{-1} on annual average; Kumagai et al. 2005) and rainforests in Peninsular Malaysia (4.2 mm day^{-1} on annual average; Tani et al. 2003). The transpiration estimate derived from sap flux measurements for the same oil palm plantation (2.5 mm day^{-1}) was the highest among the five oil palm plantations assessed in this study, and also among 15 different oil palm plantations of varying age in the greater study region (Röll et al. 2015). It was also similar to the highest transpiration rate among the four forest plots (2.4 mm day^{-1}). Our oil palm and forest transpiration estimates are similar to transpiration rates reported for tropical forest sites in Indonesia and Australia (1.3 – 2.6 mm day^{-1}; Calder et al. 1986, Becker 1996, McJannet et al. 2007). This suggests that oil palms can transpire at substantial rates under certain conditions, despite, e.g., their much lower biomass per hectare compared to forests (Kotowska et al. 2015). Among all studied plots, the sap flux-derived estimates for average oil palm and forest transpiration rates are similar, but rubber plantations transpire at more than 60% lower rates under similar conditions. Also, rubber trees partially shed their leaves in pronounced dry periods, which further reduces transpiration by up to 70% explicitly in times of water scarcity. In addition to the much lower re-evaporation of water to the atmosphere, rainfall interception by rubber plantations is 1.7-fold lower than by oil palm plantations (28% of incident rainfall); our values for interception fall into the range of values reported for tropical forests in South East Asia (commonly 10-30%, e.g., Dykes 1997, Kumagai et al. 2004, Dietz et al. 2006). The differences in transpiration and interception can explain the lower baseflow from oil palm dominated catchments as compared to rubber dominated catchments that we observed.

Soil water infiltration capacities represented by Ks-values derived from ring infiltrometer experiments for different land-use types in the study region were reported to decrease from forest (47 cm hr^{-1}) via rubber (7 cm hr^{-1} on harvesting paths, 7.8 cm hr^{-1} between rubber trees) to oil palm plantations (3 cm hr^{-1} on harvesting paths and weeding circles; S. Tarigan and Sunarti, *unpublished data*). The much lower infiltration capacities in plantations as compared to forest are consistent with the observed strong decline of soil quality after forest conversion, i.e., decrease in C content and erosion (Guillaume et al. 2015, 2016). C content plays a key-role in soil aggregation (Franzluebbers 2002, Bronick and Lal 2005), while erosion brings deeper and denser soil layers to the soil surface. Thus, both are associated with lower soil permeability. Such soil degradation after forest conversion was also observed in similar land-use types in Malaysia (Gharibreza et al. 2013), China (de Blécourt et al. 2013), and Ghana (Chiti et al. 2014). Although the extent of soil degradation was similar between rubber and oil palm plantations, soil characteristics are more heterogeneous in oil palm plantations, i.e., soil organic carbon content is lower in inter-rows (Frazão et al. 2013) and frequent and intensive management and harvesting operations increase soil compaction, e.g., on harvesting paths. The surfaces with the most degraded soil in oil palm plantations correspond to the locations where rainfall interception is low because of the incomplete canopy cover between palms (> 20% gap fraction; Kotowska et al. 2015). This may explain the higher runoff as reflected by two-fold higher relative peak flows, i.e., normalized by baseflow, in oil palm than in rubber plantations.

In conjunction with the observed higher transpiration rates of oil palm as compared to rubber plantations, the increased runoff in oil palm plantations results in significantly less water being available for groundwater recharge after precipitation than in rubber plantations, and much less than in forested areas. Thus, groundwater recharge may be less efficient in oil palm dominated catchments than in rubber dominated ones, which may add to water scarcity during dry periods. Similar reductions in dry period baseflows and increases in postprecipitation peak flows after forest conversion have been reported in a variety of studies (e.g., Bruijnzeel and Bremmer 1989, Fritsch 1990, Sandström 1995, Elkaduwa and Sakthivadivel 1999, Zhou et al. 2002, Bruijnzeel 2004, Bonell et al. 2010, Zimmermann et al. 2010).

Our findings are consistent with the "sponge and pump" approach to hydrological effects of forest conversion (Bruijnzeel 2004, Peña Arancibia 2013). Forests may act as sponges by enhancing infiltration rates and moisture retention because of the effects of organic matter and the root network on soil physical properties, and act as pumps by transpiring large amounts of water into the atmosphere (see, e.g., Peña Arancibia 2013). In our study, both land-use types replacing the forest may have reduced the sponge effect. According to the "infiltration trade-off hypothesis" (Bruijnzeel 1986, 1989, 2004), the net effects of forest conversion on streamflow largely depend on the type of land cover replacing the forest. Baseflow (in dry periods) may be as high as in forested areas if losses in infiltration capacity are outbalanced by much lower (evapo)transpiration rates in the newly established land-use systems, which is often the case. In our study, the rubber plantations are such an example. The oil palm plantations, however, are different: we found soil degradation and thus low permeability as well as a high transfer of water vapor to the atmosphere. Combined, this can induce or enhance periodic water scarcity in oil palm dominated landscapes.

5.3. Confronting perceived changes with environmental measurements

Our results suggest that rainfall volume and seasonal patterns did not change significantly since the beginning of oil palm expansion in the study region. Also, similar volumes of water are re-evaporated back into the atmosphere from oil palm plantations and forests, but the penetration of water into the soil is reduced in oil palm plantations. Thus, much precipitated water leaves the landscape as surface runoff, causing streamflow to be high during rainfall events; less water remains in the soil under oil palms than in forested areas and groundwater recharge is decreased. In consequence, wells may dry out (earlier) during dry periods in oil palm dominated regions, as it was reported by the majority of interviewed Bungku villagers. The perception of extremely high water-use rates of oil palms as the main cause for increased seasonal water scarcity among some Bungku villagers does not match the results of our evapotranspiration and transpiration measurements. However, the people's perception that the regional oil palm expansion may be responsible for local water scarcity during dry periods is backed by several results from environmental measurements. We also have indications that there are significant differences in eco-hydrological characteristics (particularly in transpiration rates) between oil palm and rubber plantations, as observed by several villagers.

Our matching of social perceptions and environmental measurements thus provides manifold explanations for changes in the physical water cycle. The major force behind these changes is the rapidly expanding oil palm business, which constitutes the main driver of deforestation and land-use change in the area (Colchester et al. 2011). Changes in the local water cycle are not only caused by soil degradation under oil palms but also through the channelization of rivers and the draining of swamp areas by oil palm companies (*personal observations* in the field and from satellite images). These shifts in the physical water flows mirror changing societal power relations that accompany the conversion of an originally forest-dominated area toward an intensively managed agroindustrial landscape (see Beckert et al. 2014, Brad et al. 2015, Hein et al. 2015). Water, a formerly abundant common pool resource, today is becoming a scarce resource during dry seasons. In such times of water scarcity, people have to reorganize their daily life around the constant "search for water." Water is consequently increasingly treated as a commodity rather than a common pool resource. This capitalization increases social polarizations in the village between winners of land-use change and underprivileged social groups such as indigenous people or poorer farmers. In the light of decreasing access to land (Colchester et al. 2011, Beckert et al. 2014, Hauser-Schäublin and Steinebach 2014, Hein et al. 2015), the access to clean water has turned into an additional argument to substantiate political claims in local contestations over access to land and natural resources. Our social and environmental analysis of different components and processes of the hydrosocial cycle in Bungku thus clearly depicts the complexity of local water-society relations. It serves as an example of how local land-use change triggers both material and discursive changes in the hydrosocial cycle, i.e., the occurrence of local water scarcity as well as its local interpretation by different social groups.

6. Conclusions

Water shortages were reported to occur more often since oil palm cultivation has become the dominant land use and large-scale deforestation has taken place. Several villagers strongly emphasized that oil palm is a major consumer of water and thus largely responsible for decreasing local water tables and water supplies. Analyses of environmental processes generally supported this perception and also confirmed differences between rubber and oil palm plantations. However, there is some added eco-hydrological complexity to the local interpretations. Our evapotranspiration data indicate that oil palm plantations use about as much water as forests for transpiration. Rather than to high water use of oil palms per se, local water scarcity seems connected to the redistribution of water after precipitation at the landscape scale. In natural ecosystems, e.g., forest, the largest part of rainfall water is taken up by the soil and contributes to the transpiration of plants and groundwater recharge. Under oil palm plantations, however, precipitated water cannot well penetrate the eroded and compacted soil. Consequently, a significant amount of water leaves the landscape as runoff and less water is available for groundwater recharge. Large-scale conversion of natural forests to oil palm plantations thus induces or enhances periodic water scarcity.

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Author Contributions

Jennifer Merten and Alexander Röll contributed equally to the study in terms of coordinating, contributing data and ideas, and the amount of time spent writing and revising the manuscript. Jennifer Merten coordinated the human dimensions part of the study, Alexander Röll the natural science part.

CHAPTER III:

Flooding and land use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry

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Abstract

The rapid expansion of rubber and oil palm plantations in Jambi Province, Sumatra, Indonesia, is associated with largescale deforestation and the impairment of many ecosystem services. According to villagers' observations, this land use change has, together with climate change, led to an increase in the magnitude and frequency of river flood events, which constrain village and plantation development. Based on this empirical societal problem, we investigate whether we can find measurable indications for the presumed linkages between land use change, climate change, and changing flooding regimes. We follow an explorative, bottom-up research approach that builds on a review of multidisciplinary datasets, integrating local ecological knowledge with scientific measurements from soil science, climatology, hydrology, and remote sensing. We found that water levels of one of the largest rivers in Jambi Province, the Tembesi, have increased significantly during the last two decades. Data of local and regional meteorological stations show that alterations in rainfall patterns may only partly explain these changes. Rather, increased soil densities and decreased water infiltration rates in monoculture plantations suggest an increase in surface runoff following forest conversion. Moreover, additional interview data reveal that an increasing encroachment of wetlands in Jambi Province may contribute to changes in local flooding regimes, as the construction of drainage and flood control infrastructure redistributes floodwater at the local scale. We conclude that changing flooding regimes are the result of multiple interacting social-ecological processes associated with the expansion of rubber and oil palm plantations in Jambi Province. Although ecohydrological changes are likely to contribute to an increase of flood occurrence, their social impacts are increasingly mediated through flood control infrastructure on industrial oil palm plantations.

Key Words: *ecohydrology; flooding; global change; Indonesia; interdisciplinary analysis; land use conversion; local ecological knowledge; oil palm; rubber*

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1. Introduction

In the past, flooding occurred rarely. ... Back then, most people didn't plant oil palm, didn't plant rubber. ... It started, because the forest is already gone. That's why nowadays flooding occurs so often. ... For annual crops, if flooding occurs more often, that's a problem. ... [Sometimes] when the farmers had just planted the seedlings, then suddenly flooding occurred.

Rubber farmer, Jambi, Sumatra, Indonesia

In Southeast Asia, large areas of lowland forests have been converted to oil palm, rubber, and pulp wood plantations over the last decades (Hansen et al. 2013, Margono et al. 2014, Clough et al. 2016). For example, in 2015, oil palm plantations in Malaysia and Indonesia covered an area of 17 million ha (Chong et al. 2017). Such intense land use change is often followed by an impairment of ecohydrological functions (Bruijnzeel 2004, Bradshaw et al. 2007, Ellison et al. 2017). Several studies have recently started to connect the expansion of rubber and oil palm monoculture plantation systems with increases in the frequency and intensity of flooding.

The existing studies build on a variety of methodological approaches. Hydrological measurements showed that oil palm monoculture plantations may have low soil water infiltration rates (Tarigan et al. 2018) as a consequence of severe soil degradation and erosion (Guillaume et al. 2015, 2016). Particularly in combination with low evapotranspiration rates of young oil palm plantations this may increase surface run-off and the risk of flooding in oil palm dominated landscapes (Manoli et al. 2018, Tarigan et al. 2018). These findings also correspond with a time-series analysis of streamflow data that found evidence for increasing streamflow through upstream land use conversion to rubber and oil palm plantations (Adnan and Atkinson 2011). Other approaches have built on spatial analyses and econometric modeling. For example, Tan-Soo et al. (2016) and Wells et al. (2016) found rubber and oil palm plantations to be spatially associated with reports of increasing flooding occurrence in Malaysia and Indonesia. Finally, a number of studies conducting qualitative social research present interview data from villagers across Indonesia who associated land use change, toward monoculture plantations, with increasing flood occurrence (Obidzinski et al. 2012, Larsen et al. 2014, Kelley and Prabowo 2019).

Such a linkage between the expansion of plantations and flooding was also observed by villagers in our study area in Jambi Province, Sumatra, as pointed out in the above quote from a smallholder farmer. In times of rapid land use change for global cash crop production, understanding such processes is of great relevance for the affected communities. Although the above-mentioned studies provide some evidence of changing flooding regimes due to plantation expansion, most of them present compartmentalized insights from single disciplines. A substantial gap in knowledge about the multiplicity of causal processes between land use change, climate change, and river water levels remains in our study region and beyond.

Establishing the linkage between land use change and flooding has been a long and contested endeavor among natural as well as social scientists (Calder and Aylward 2006, Bradshaw et al. 2007, van Dijk et al. 2009, Lele 2009). In public discourses, deforestation is often linked to an increase in the frequency and intensity of flooding. In fact, tree and forest removal is well known for raising the likelihood of floods, as decreasing evapotranspiration rates and decreasing water infiltration increase local surface runoff (Ellison et al. 2017). However, after deforestation, such processes may be reversed. Water infiltration rates may recover and evapotranspiration rates by planted tree species may then be as high as those of natural forests (Bruijnzeel 2004). Natural scientists have further cautioned that linkages between land use change and flooding regimes often depend upon the interaction of multiple, site-specific ecohydrological processes, including local climate change (Bradshaw et al. 2007, Alila et al. 2009, Locatelli and Vignola 2009, van Dijk et al. 2009, Tran et al. 2010, Pattison and Lane 2012). Social scientists, for their part, have warned that a generalization of the forest-flood linkage may result in policies with adverse social consequences, e.g., upstream forest dwellers being restricted in their land use activities and falsely blamed for causing downstream flooding (Saberwal 1998, Calder and Aylward 2006, Hofer and Messerli 2006). Moreover, they have pointed out that studies within the natural sciences often ignore the social and technical context that mediates flood impacts as well as response and feedback processes (Lele 2009, Di Baldassare et al. 2014).

Integrating local ecological knowledge into scientific analysis can address some of the above-mentioned uncertainties and risks when studying complex social-ecological phenomena (Pierotti and Wildcat 2000, Fabricius et al. 2006, Stringer and Reed 2007, Tengö et al. 2014, Leimona et al. 2015, Días et al. 2018). Such an integration of different knowledge sources may also enable research outcomes to be socially and practically more relevant in the local social context and is considered an important step toward democratizing explanations of environmental change (Forsyth 2003).

In this paper we aim to provide an integrated analysis of linkages between land use change, climate change, and flooding regimes by combining qualitative interview data on local ecological knowledge with scientific measurements. We examined multidisciplinary datasets to identify potential social-ecological processes that could explain the villagers' observations of increases in flood frequency and intensity following forest conversion in the Tembesi watershed in Jambi Province (Sumatra, Indonesia).

Our research objectives are the following: building on qualitative interviews, we (1) review villagers' observations of changes in patterns and intensity of flood events as well as their evaluations of changing environmental processes. We then (2) test whether the reported changes in flooding regimes are mirrored in available stream flow data from the Tembesi River. Building on the villagers' evaluations of the potential causes for changing flooding regimes, we test whether changes in climate and/or in land use can provide explanations for the observed changes. Therefore, we (3) analyze local precipitation patterns for changes over the last decades, and (4) compare hydraulic soil properties in different land use systems. More specifically, we quantify land use change in the Tembesi River watershed (1990–2013) and assess whether soil bulk densities (as an indicator of soil compaction), water infiltration capacities, and groundwater levels of oil palm and rubber plantations differ from forests and less intensively managed reference systems. Finally, based on villagers' specific concerns for land use change in wetland areas, we (5) investigate whether forest conversion in wetland areas has further contributed to an alteration of flooding regimes. To this aim, we analyze the land use history as well as land use characteristics of wetland areas, building on land use data (1990–2013) as well as on a comparison of qualitative case study data within the Tembesi watershed.

Finally, we integrate these multiple knowledge sources by discussing convergences, complementarities, and divergences among datasets. Although our study design was not a priori designed to answer questions related to flooding specifically, we show that an a posteriori analysis of different knowledge sources can be an important tool for interdisciplinary research. It can also provide a more complete analysis of the complex linkages between land use change and flooding.

2. Conceptual framework

Our research approach builds on the tradition of critical realist approaches in political ecology and sustainability sciences. These studies emphasize the need for problem-driven, bottom-up research approaches that integrate different knowledge sources to find locally framed explanations of environmental problems (Forsyth 2003, Walters and Vayda 2009, Lele and Kurien 2011, Thorén and Persson 2013, Ribot 2014).

Studies on flooding and flood impacts in the context of land use change are often dominated by accounts from the natural sciences. Changes in flooding regimes are mainly derived from direct ground-based measurements using water level or discharge data from flood gauges (e.g., MDID 1989, Yusop et al. 2007, Adnan and Atkinson 2011), or modeling exercises. Model inputs are typically based on direct field measurements of the different components of the hydrological cycle, such as soil surface runoff, infiltration rates, throughfall, or evapotranspiration rates (e.g., Manoli et al. 2018, Tarigan et al. 2018). Precipitation quantities are either obtained from satellite-derived precipitation and cloud cover estimates (Maggioni and Massari 2018), or based on combined field and satellite measurements (Kwak 2017). In recent years, satellite imagery has become a widely used tool for monitoring flood events on a large scale. However, optical-based satellite imagery has its limitations because of cloud cover, especially in the tropics (Ahamed and Bolten 2017, Ban et al. 2017, Adam et al. 2018, Notti et al. 2018). Typical indicators for changing flooding regimes include the number of days with extreme water levels or peak flows, average water level rise as an indicator for flash floods, average seasonal water levels, or shifts in seasonal water levels (Dang et al. 2011, Wang et al. 2015).

These approaches, however, have a number of limitations with regard to data availability and the integration of the human dimension. In the study of flooding regimes, local people's ecological knowledge may thus fruitfully complement scientific measurements. Local ecological knowledge (sometimes also referred to as traditional ecological knowledge) comprises three components of knowledge: observational knowledge, knowledge acquired through practical experience, and knowledge in the form of people's beliefs (Berkes et al. 2000). Such knowledge is acquired through personal empirical observation and interpretation of local ecosystems, and enriched and validated through exchange with other farmers and villagers (Berkes et al. 2000, Usher 2000, Houde 2007).

In particular, the integration of observational and practical local ecological knowledge may provide several benefits for establishing a link between land use change and flooding regimes. First, local ecological knowledge provides fine-grained information about ecosystems in areas where little scientific knowledge exists, such as rural Sumatra (Fabricius et al. 2006). A typical problem of scientific measurements is that field measurements are often only available at plot scale. On the other hand, modeling exercises conducted at larger scales often provide little information about factual changes in flooding regimes, e.g., at the village level. Integrating people's knowledge might also be useful for detecting environmental changes that are not immediately apparent in short-term scientific measurements as local people get to observe things more often, over longer periods, and in a wider variety of places (Usher 2000). Thereby it might draw attention to environmental change that otherwise would possibly not be studied. For example, Wells et al. (2016) integrated interview data with newspaper reports of flooding and watershed characteristics to show that flooding is far more widespread than reported in government assessments. Moreover, local ecological knowledge is considered to be holistic in nature, compared to scientific studies that are often compartmentalized (Pierotti and Wildcat 2000, Fabricius et al. 2006, Aikenhead and Ogawa 2007). Integrating local ecological knowledge in the study of land use change and flooding may thus enable more open research approaches, which could better account for multiple and interacting processes in the generation of flood events.

Second, both field measurements and modeling exercises often fail to adequately incorporate the human dimension of the problem, both with regard to defining what constitutes a problematic change in flooding as well as with regard to potential human influences on water flows (Lele 2009, Di Baldassare et al. 2014, Langill and Abizaid 2020). Lele and Kurien (2011) thus call for a shift from theory-driven to problem-driven, bottom-up research, to avoid research questions that are only determined by what the researcher is trained in. For example, by questioning what actually constitutes a "bad flood," Langill and Abizaid (2020) showed that studies of extreme floods within the natural sciences typically focused on unusually high floods. In their study, they showed that for a floodplain community in the Peruvian Amazon the timing and duration of flooding were in fact the most salient features of problematic floods. Existing studies connecting land use change in Indonesia and Malaysia to changing flooding regimes either investigated streamflow fluctuations independent of human evaluation (Adnan and Atkinson 2011) or looked at the number of flood events reported by newspapers and government assessments (Tan-Soo et al. 2016, Wells et al. 2016).

Integrating local ecological knowledge into the study of land use change and flooding may also help to draw attention to the social and technical context that mediates flood impacts. This integration may further contribute to an understanding of how changing flooding regimes may trigger people's response and feedback processes that shape water flows in turn (Lele 2009, Di Baldassare et al. 2014). For instance, Kelley and Prabowo (2019) use oral histories to reveal social transformation processes set in motion by changing flooding regimes. These transformation processes were shown to increase the people's systemic vulnerability to flooding as well as producing feedbacks of altering river flows.

Although multiple opportunities for integrating local knowledge and scientific measurements exist, the pitfalls of integration have also been discussed at length and, at times, in a controversial manner (Klubnikin et al. 2000, Pierotti and Wildcat 2000, Moller et al. 2004, Bohensky and Maru 2011, Persson et al. 2018). Similar to the integration of methods from qualitative social science and quantitative natural science, it has been pointed out that ontological and epistemological differences between knowledge sources may hinder output-oriented knowledge integration (Nadasdy 1999, Krüger et al. 2016, Thorén and Stahlhammer 2018). In particular, in-depth confrontations between different ontological understandings and assumptions, or critical engagements with other approaches for establishing scientific quality and validity of methods, are often limited by time constraints. Despite such concerns, we argue that more pragmatic approaches that foster interdisciplinary research are both possible and valuable. An important condition for overcoming challenges of integration is a common framing of the research problem. Several scholars have therefore recommended taking an empirical societal problem as a starting point of analysis, i.e., observations of increasing flood occurrence (Walters and Vayda 2009, Lele and Kurien 2011, Thorén and Persson 2013). Explanations from different disciplines and knowledge sources may then be reconciled by seeing each as partial, context-specific, and potentially fallible, but acknowledging that the combination of different sources may provide better understandings of environmental problems (Yeung 1997, Forsyth 2003, Lele and Kurien 2011).

3. Study region and methods

Our study region, Jambi Province, lies in the eastern lowlands of Sumatra, Indonesia. In Jambi Province, 7942 km^2 of forest were cleared between 1990 and 2013, which corresponds to 35.2% of the 1990 forest area (Melati 2017). Most land use changes have taken place in the lowlands of Jambi Province, which today are dominated by monoculture rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis* Jacq.) plantations. Monoculture rubber plantations have been developed in Jambi Province since the Dutch colonial times (Feintrenie and Levang 2009); oil palm cultivation started in the mid-1980s and has expanded to almost 9000 km^2 (18% of the province's territory) in 2017 (BPS Indonesia 2018).

The lowland rivers of Jambi Province show strong seasonal fluctuations between the dry and the wet season. Consequently, large areas in the province's lowlands are inundated during the rainy season. In the Batanghari watershed (44,595 km^2), the largest watershed in Jambi Province, 2282 km^2 of land across 222 villages is affected by regular flood events (Minister of Public Works 2012).

Our paper presents findings with a focus on the lowlands of the Tembesi watershed, the largest subwatershed of the Batanghari (12,819 km^2). This focus was chosen because of the dynamic land use change in this area, the number of people affected by flooding, as well as data availability. The watershed's lowlands cover large wetland areas, which include peatland areas of around 440 km^2 (see Fig. 1; Wahyunto and Subagjo 2003, Biagioni et al. 2015). Today, land use in the lowland areas of the Tembesi is dominated by agriculture, mainly oil palm and rubber plantations that account for 52% of the watershed's area (see Fig. 1; Melati 2017). The climate in the watershed's lowlands is tropical humid (annual average air temperature of 26.5 °C, annual precipitation of 2235 mm $year^{-1}$) with a wet season from October to May (Sulthan Thaha meteorological station, as cited in Drescher et al. 2016). According to data published in local newspapers, the typical seasonal fluctuations of the Tembesi water levels in the watershed's lowlands vary between 5 and 11 m (Anton 2017, Saputra 2017). All data analyzed for this study was obtained within the EFForTS collaborative research center (https://www.uni-goettingen.de/en/310995.html)

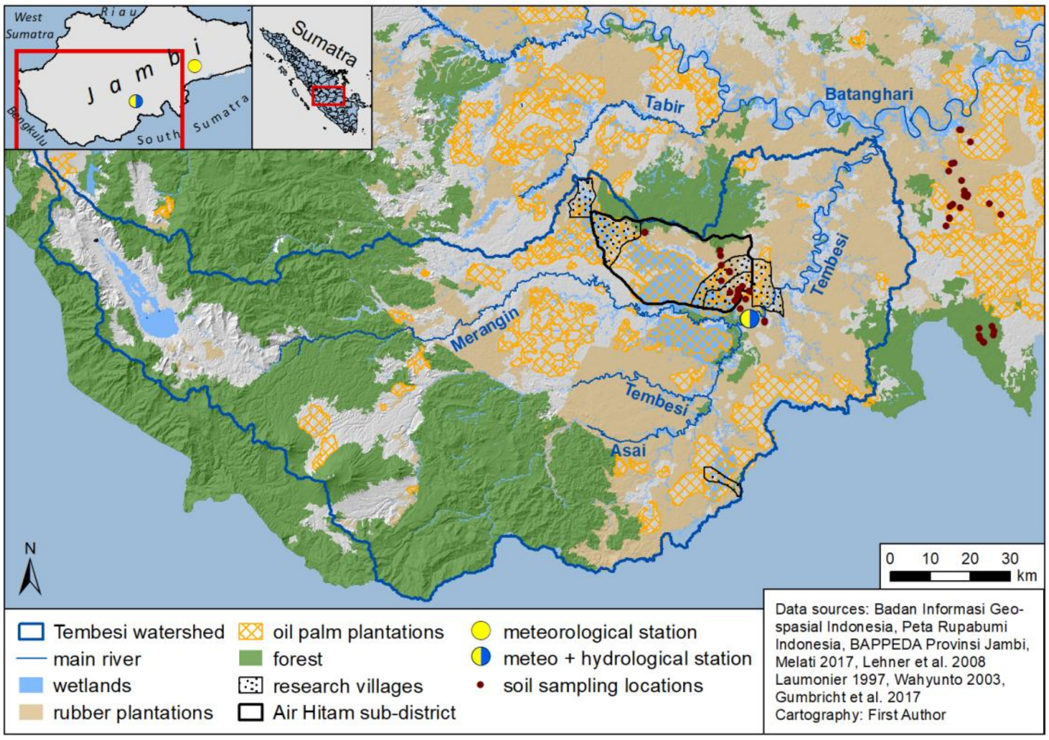

Fig. 1: Study region of the Tembesi watershed in Jambi Province, Sumatra, Indonesia.

3.1. Qualitative interview data

Our analysis builds on two different sets of qualitative interview data obtained from semistructured and informal interviews (total number of interviews = 91; Bernard 2011). All interviews were conducted during long-term (2–6 months) field stays in Jambi Province between 2012 and 2017. Interviews were conducted in English and Indonesian with the help of local assistants. Detailed notes and memos were written down during or shortly after the interviews. In addition, audio-recorded interviews were transcribed in Indonesian. All interview notes as well as excerpts from transcripts were coded for content (Mayring 2000) using MAXQDA (V. 11) software.

Local ecological knowledge on changing flooding regimes

Interviews of the first dataset were mainly conducted in the subdistrict Air Hitam (Fig. 1). In this subdistrict, three villages were chosen along an upstream-downstream continuum of the eponymous Air Hitam River. In this subdistrict, interview partners from 33 different households were interviewed. Interview partners were chosen according to snowball and purposive sampling methods (Flick 2016). Purposively selected interview partners included village government representatives, heads of farmer groups, village elders, and villagers who were directly affected by flood events, either on their housing plot or on their plantations. In addition to the households in the Air Hitam subdistrict, eight households, who own plantations in riparian areas that were also sampled for soil property analyses within the frame of this study, were purposively selected for interviews. Several of the interview partners were interviewed repeatedly during consecutive field visits, combining both formal and informal interview situations, and often involving family members or friends present during the interview situation (total number of interview situations n = 69). The interviews focused on interrogating people's observations of changes in local flooding regimes, their individual evaluations of possible causal relations and the implications for the individual households.

Local knowledge on land use history and management of wetlands

Because of the interview partners' specific concern about land use change in wetland areas, an analysis of the second dataset aimed to explore the specific land use characteristics of wetland areas in the Tembesi watershed. Therefore, we compared land use history and management of wetland areas across six villages, the territories of which include vast wetland areas. In addition to the three villages in the Air Hitam subdistrict, our case study comparison comprised three further villages within the lowlands of the Tembesi watershed. Interviews conducted in these villages included data from former investigations within the EFForTS research project (Kunz 2016, Rödel 2018) that were made available for this study (additional number of interviews n = 22). We define wetland areas as areas where water covers the soil or is near the surface of the soil either permanently or temporarily (Ramsar Convention Secretariat 2016). This includes riparian floodplains, swamps, as well as peatlands.

The presence of a foreign researcher most certainly influences the way interview partners recount a certain topic, e.g., by providing an answer they expect will please the researcher (Berger 2015). We aimed to reduce such response biases through conducting long-term qualitative research with repeated visits to the studied villages. Qualitative interview techniques were chosen as a method because they allow for bottom-up and in-depth analyses of people's evaluation of local environmental change. Contrary to predefined questionnaires, the use of open-ended questions and a more natural and spontaneous course of conversation allows researchers to create trusting and less formal interview situations. These are helpful for avoiding response biases because they allow the researcher to encourage interview partners to recount environmental changes on their own initiative. They further provide room for more detailed descriptions of environmental changes and reveal insights into the importance of flooding for people's daily life. Information obtained during interviews was then cross-checked in subsequent interviews with interview partners from different social groups. Finally, interview data was triangulated with participative observation, including several visits to villagers' plantations and different river sections.

3.2. Quantitative scientific measurements

River water level

The water level of the Tembesi River was measured at Pauh hydrological station (02°08′55″ S, 102°48′22″ E), which is located at the mouth of the Air Hitam River to the Tembesi River (Fig. 1). The data for this analysis was provided by the Public Works Agency for Water Resources (Dinas Pekerjaan Umum Bidang Sumberdaya Air) and covers the period 1997–2016. The river catchment area at Pauh hydrological station covers an area of 10,760 km² (84% of the Tembesi watershed). Water levels were recorded once per day between 8 and 9 am, local time, with an automatic water level recorder that uses a floating ball as a mechanical trigger (Roni 2005). River discharge was derived from a site-specific rating curve.

Based on villagers' observations of changing flooding regimes and building on the approach of Wang et al. (2006) and Zhang et al. (2009), we analyzed a potential increase in flood frequency and intensity as well as potential shifts in seasonal patterns of flood events. For this purpose we investigated (a) the number of days with extreme water levels of the Tembesi River, (b) the average water level rise as well as the frequency and intensity of flash floods, and (c) the average seasonal water level and possible changes. For (a) we defined extreme water levels as water levels when the Tembesi River overflows its natural dams (11 m). This threshold is based on the reported typical water level of 5–11 m (Anton 2017, Saputra 2017) and double checked with river water level data for days when flood events were reported in the local online newspaper or by the National Board for Disaster Management (BNPB 2019). For (b) we compared the change in water levels between two subsequent days over the period 1997–2016 and defined a flash flood as an event with water level rise > 1 m over two consecutive days. For (c) we calculated the mean water level for each month.

Precipitation

The only lowland meteorological stations in the vicinity of our study region that offer long-term meteorological measurements are at Jambi Sultan Thaha Airport (01°38′17″ S, 103°38′40″ E, 25 m a.s.l.), which has been taking measurements since 1978, and in the village Pauh (02°11′09.6″ S, 102°49′01.1″ E, 43 m a.s.l.), where measurements have been available since 2007 (Fig. 1). Both meteorological stations are owned and run by the Indonesian Meteorological Service (BMKG). The areal distance between the two meteorological stations is approximately 110 km and the areal distance between the Pauh meteorological and hydrological stations is approximately 4 km. Both meteorological stations are located inland, within similar land use structures and relatively flat terrain. Precipitation pattern in the lowlands are mostly dominated by very local and temporary convective rain showers. Precipitation patterns and intensities may thus differ substantially even within small distances. We analyzed monthly accumulated precipitation, precipitation intensity, and seasonal distribution. Precipitation intensity for both meteorological stations was calculated following the SDII climate index (Zhang et al. 2011), where the total sum of precipitation during consecutive wet days (precipitation > 0.1 mm d^{-1}) is divided by the total number of consecutive wet days.

Land use change

Our land use change analysis builds on a comparison of existing land use maps for Jambi Province from 1990 and 2013 (Melati 2017). For the purpose of this study, the land use classes were reclassified to fit our research questions and land use maps were reanalyzed for the section of the Tembesi watershed.

The maps elaborated by Melati (2017) were based on mixed land use/land cover maps originally developed by the Indonesian Ministry of Environment and Forestry (MoEF; Margono et al. 2016). The classification of these land use/land cover maps was based upon a visual interpretation of 30 m spatial resolution Landsat imagery with a minimum mapping unit of 6.25 ha. The original 23 classes defined by Margono et al. (2016) were enhanced further in a subsequent visual interpretation by Melati (2017) who regrouped some of the former land use/land cover classes to fit land use in Jambi Province. During this enhancement, formerly categorized estate crops were further differentiated into rubber and oil palm land use systems. For this study, we grouped the resulting land use classes by Melati (2017) into the seven most relevant land use classes, namely forest, mixed agriculture, bush/bare land, rubber plantations, oil palm plantations, settlement, and water.

To map wetland areas, we combined available wetland maps for Jambi Province, elaborated by Gumbricht et al. (2017; https://www2.cifor.org/global-wetlands/), Wahyunto and Subagjo (2003), and Laumonier (1997). An additional land use change analysis was performed on these areas using the land use data provided by Melati (2017).

Soil bulk density and water infiltration capacity

Published bulk density data (g cm^{-3}) from well-drained sites (Allen et al. 2016) as well as unpublished data from riparian sites were used to evaluate soil compaction after the conversion of forests to monocultures. Bulk density samples were weighed and dried at 105 °C until constant weight. The data consisted of five replicates per site and soil depth. Sampling depth intervals were 0–10 cm, 10–30 cm, and 30–50 cm soil depth. Sampling sites represented six sites from reference forests, six from rubber, and six from oil palm plantations on well-drained mineral soils as well as four sites of each land use system on riparian soils. Three well-drained mineral soil sampling sites were located within the Tembesi watershed whereas three well-drained mineral sampling sites, as well as the riparian soil sampling sites, were located just outside the watershed, but within the same lowland of Jambi province (Fig. 1). Acrisols with a clayish to sandy loam texture were the dominant soil type in well-drained mineral soils (Guillaume et al. 2015), whereas riparian soils were classified as stagnic Acrisol and Stagnosols with a loamy texture (Waite et al. 2019).

To assess the water infiltration capacity of soils, we measured saturated soil hydraulic conductivity (K_{fs}, cm h^{-1}), which describes the movement of water through soil under water-saturated conditions. The main measurements were performed with a dual-head infiltrometer (Saturo, Meter, USA) in a commercial oil palm plantation where a biodiversity enrichment experiment was established in 2013 (EFForTS-BEE; Teuscher et al. 2016). In this experiment, multiple native tree species were planted and natural regeneration of the vegetation was allowed. The experimental plots have varying tree diversity levels (from 0 to 6 native tree species) and plot sizes (from 25 m^2 to 1600 m^2) following a random partition design (Teuscher et al. 2016). We carried out one measurement per plot in March 2018 in the subplot in four control plots (management-as-usual oil palm monoculture plantation) and 33 experimental plots where different tree species have been planted and vegetation regenerates naturally (see Table A1.1). We carried out additional, confirmatory measurements of K_{fs} with a conventional manual double-ring infiltrometer in a commercial, intensively managed monoculture oil palm plantation in the same region (PTPN VI, at approx. 40 km distance from the biodiversity enrichment experiment). Six study plots were measured between June and September 2018.

Groundwater level

To investigate the effect of the land use system on groundwater level, we measured groundwater levels in oil palm and rubber riparian monocultures as well as in forest riparian locations with an OTT Orpheus Mini water level logger (OTT HydroMet GmbH, Kempten, Germany). Measurements were conducted at the same 12 riparian locations that were also sampled for soil bulk density. The logger was installed at a depth of between 2.5 and 4.5 m in a metal borehole equipped with a fine sieve on its lower end. Data was available from July 2017 to March 2019 at four different locations for each of the three land use systems (forest, rubber plantation, oil palm plantation).

Statistics and data analyses

We applied the Mann Kendall Trend Test (M-K test; Gilbert 1987) to investigate possible changes in the seasonal and monthly pattern of river water level and accumulated precipitation. The M-K test τ ranges from -1 to 1 where values above 0 indicate a positive trend whereas values below 0 indicate a negative trend and trends are significant for $p < 0.05$. To test for statistical differences in soil bulk density and K_{fs} between different land use systems, we performed a nonparametric Kruskal-Wallis Test (differences are significant for $p < 0.05$; Townend 2004). All statistical analyses and graphing were performed using R-studio (version 1.1.463), except for the land use change analyses, which were performed in ArcMap (version 10.6.1) and Excel and visualized with the help of the online tool sankeyMATIC (http://sankeymatic.com/).

4. Results

4.1. Qualitative interview data

Local ecological knowledge on changing flooding regimes

Of 33 interview partners in the Air Hitam subdistrict, 29 mentioned having perceived changes in the intensity, frequency, or predictability of flooding over the last 10–15 years. A common observation among villagers was that flooding nowadays would occur faster, and even after short rainfall events. In their memory, flooding in the past had only occurred after prolonged rainfall (Table 1: Q1). Heavy flood events, in the past common at a return period of about five years, nowadays were said to occur almost every year (Table 1: Q2). Moreover, villagers complained that contrary to former seasonal patterns of flooding, today, the timing of flood events was no longer predictable (Table 1: Q3). Only five farmers residing in wetland areas had noticed decreases in flood height and length, which in most cases can be explained by drainage activities on these lands.

Table 1: Quotes illustrating villagers' perceptions of changing flooding regimes. (Translations by J. Merten)

Perceptions of changing flooding regimes	
Q1: "[The flooding in the past] was different, very different. In the past when it only rained for one day, the river did not directly overflow. But now, after one hour of heavy rain, it already overflows. […] It started to be like that ever since many people opened the land for oil palm. […] Now, there is constant flooding."	rubber farmer (riparian plantation, 14 Nov. 2017)
Q2: "Flooding happened since the past. But as far as I remember, in the past flooding occurred rarely, and it was rarely very high. Sometimes, once in five years there was a big flooding, but now it happens almost every year."	village gov. representative (Air Hitam, 13 July 2016)
Q3: "Now it is difficult to predict [the flooding]. Normally, […] starting from October, November, December, there would be flooding. But last year, in May, and in April, there was flooding as well. We cannot predict it anymore. In the past, when the forest was still wide, we could still predict the flooding."	village gov. representative (Air Hitam, 7 June 2016)

Explanations given for these observed changes in flooding regimes were multiple. In total, 25 of the interview partners associated changes in intensity and frequency of flood events directly with land use change and plantation management. They agreed that flooding regimes started to change after vast forest areas had been converted to rubber and oil palm plantations. Because of this conversion, according to them, the capacity of the landscape to "retain" or "save" water had decreased. Among the villagers, forests were known to "hold back" rainwater and release it only slowly to the rivers (Table 2: Q4). Individual interview partners referred to forests as acting as a "protective shield" that would prevent the occurrence of natural disasters (Table 2: Q5).

The capacity to store water in the landscape was attributed to forest areas, but not to plantations. Some farmers had observed that rainfall in their plantations could not be absorbed and retained by the soil (Table 2: Q6). Others further observed that rainfall in their plantations had flushed away large quantities of soil. This soil was then observed to flow into the rivers where it would result in shallower riverbeds (Table 2: Q7). In addition to the protective function of upstream forest areas against flood occurrence, individual interview partners also highlighted this function in regard to swamp and peat areas. As a village head recounted, before these peatlands were converted to oil palm plantations, they had absorbed and stored large amounts of water (Table 2: Q8).

Perceived causes for changes in the temporal predictability of flood events were not as consistent as for changes in flood frequency and intensity. Some interview partners associated seasonal changes in flood events with land use change (Table 1: Q3, Table 2: Q8). Others, however, also perceived that rainfall would no longer follow seasonal patterns and had become difficult to predict (Table 2: Q10).

Villagers owning land close to rivers had further noted a very recent (3–5 years) change in flooding regimes. This change was attributed to the construction of flood control infrastructure by oil palm companies managing wetland areas. Newly constructed dams and drainage gates were reported to lead to a redistribution of floodwaters. These were blamed for increasing the length and depth of flood events on smallholder farmers' plantations located adjacent to or downstream of such infrastructure and further complicating villager's prediction of flood events (Table 2: Q9 and Q10).

The reported increases in flood frequency and intensity have significant socioeconomic impacts for villagers in our case study villages. Increases in flood frequency, as well as difficulties in predicting seasonal flood events, are of particular importance to food crop farmers, who often cultivate riparian floodplains (see introductory quote of this article). For such crops, unexpected flood events, according to our interview partners, often imply complete harvest failures. According to interview partners, but also documented in government reports and local media, such harvest failures caused by flooding constitute a major reason for food crop farmers to convert their fields into oil palm plantations (Bakhori 2010, The Jakarta Post 2014, Jambi Provincial Government 2016). For the interviewed rubber and oil palm farmers, increases in flood frequency and intensity often imply a reduction of tree and palm productivity as well as an impairment of harvesting activities, fertilization, and the transport of plantation produce. Moreover, villagers residing in settlements adjacent to rivers reported being evacuated from their houses several times during the past years.

Table 2: Quotes illustrating villagers' evaluations of possible causes of changing flooding regimes. Translations by J. Merten

Possible causes of changing flooding regimes	
Deforestation	
Q4: "In the past the water did not flow down that strong, because it was held back by the trees. But now, as soon as it rains there will be flooding. All the water accumulates in the branches of the river."	elderly villager (Air Hitam, 1 Nov. 2017)
Q5: "[The trees] hold back the rain, so that not all the rain falls down. Then we have less flooding. But if all the rain falls down, on the earth, the flooding will be higher. [...] Because the forest has already been cut, that's why. The forest can absorb all the disasters."	elderly indigenous man (Air Hitam, 16 June 2016)
Soil degradation	
Q6:"Maybe it also changed because in our area, the water infiltration is already less. The area where the water can infiltrate is already less, but in the past there was still a lot of forest. So however big the rain was, maybe it was quickly absorbed by the earth, by the soil. But now […] as soon as it rains maybe the water does not enter the earth anymore, it directly flows to the river."	rubber farmer (riparian plantation, 14 Nov. 2017)
Q7: "The difference is that in the past there was rarely flooding. Because there was no erosion, there were still main other trees. The river was still deep, but now the river is shallow [...] because the soil slides off into the river, that's why it is shallow, that is why floods today happen easily."	rubber farmer (riparian plantation, 15. Nov. 2017)
Ecological function of wetlands	
Q8: "Nowadays, we cannot predict the seasons anymore. [...] Each time it rains, there is flooding. [...] In the past the forest was wide, but now it is all oil palm, that's why the water is absorbed slowly. And also all the peatlands have been destroyed. In the past, when there was still peat, all the water was absorbed by the peat."	village gov. representative (Air Hitam, 15 Aug. 2016)

Water infrastructure	
Q9: “My oil palm in the past never got flooded, but now the water is deep and the oil palms cannot be harvested. Because the water cannot spread anymore. In the past it could flow over there [direction of peatlands], but now it is blocked by the company’s dam, and then the water flows over here. In the past the water flowed to [village name]. The water split [into several arms], but now, because there is the dam, the water flows to the village.”	oil palm farmer (Air Hitam, 21 July 2016)
Q10: “In the past, before there was a dam built around inti [the company’s plantation], the flooding would drop fast. Now because of the dam, it takes longer for the water level to drop. The water comes fast, but drops slowly. […] [Before the dam was built] the flooding lasted two days, and then it would drop for two days. After five days the water was already gone. […] But now, it lasts at least half a month, if it is a big flooding.”	oil palm farmer (Air Hitam, 22.06.2016)
Climate change	
Q10: “The seasons are not certain anymore today […] Normally, the flooding seasons starts in November, […] [It] lasts 4 months. But because there is a change in the weather, we cannot predict it anymore. […] The amount of rain nowadays is not certain anymore. […] In the past it was comfortable. […] Our ancestors, when they wanted to plant rice, they would count the day, would count the month. […] But now it is difficult because of the change, the change in the weather.”	rubber farmer (riparian plantation, 14 Nov. 2017)

Land use history and management in wetland areas

To analyze land use history and management in wetlands areas in the Tembesi watershed we compared interview data across six case study villages with vast wetland areas. Interviews revealed that wetland areas in our case study villages were only extensively used before the mid-1980s. In autochthonous villages, riparian floodplains were traditionally cultivated only during the dry season and mainly planted with staple crops such as dry rice, corn, or soybean. Shallow swamp areas were partly used for wet-rice cultivation. Deeper swamp and peatland areas, on the contrary, mainly remained forested.

Starting in the mid-1980s, forested wetlands in our case study villages were progressively converted into plantation systems. At that time a national resettlement program (*transmigrasi*) aimed, inter alia, at the economic development of supposedly undeveloped areas across Jambi Province, including expansive peatland areas (for more details see Fearnside 1997). Three of our case study villages were established under this program. Following the establishment of these villages, peat swamp forests adjacent to them were converted into industrial oil palm and rubber plantations. These plantations were jointly managed by settlers and industrial companies. In the other three autochthonous villages, plantations expanded into wetland areas more recently, starting around the early 2000s. A profitable plantation development on these soils requires substantial financial and technical capital for water management. Therefore, villagers interviewed argued that the conversion of wetland forests was mainly initiated by independent private and commercial investments that progressively expanded into areas that were formerly considered marginal. Smallholder farmers who independently tried to develop these areas often sold their land or left it only sporadically managed.

Nowadays, wetland areas in all studied villages are almost exclusively planted with monoculture oil palm plantations. According to the interview partners, the oil palm is the only crop known that can be profitably managed in inland wetlands. A rubber plantation developed on peat soils in one of the transmigration villages had been abandoned after a few years because of extremely low productivity. Annual crops planted in wetland areas have decreased in extent over the past decades because of economic disincentives as well as the above-mentioned challenges associated with changing flooding regimes.

Changes in local flooding regimes appear to also concern companies and private investors who own oil palm plantations in the wetlands of our case study villages. Prior to plantation development, these had typically established large-scale drainage systems on their lands. In several cases, however, these drainage systems have recently been complemented with flood protection infrastructure such as flood control dams. Along the Air Hitam River, at least three larger oil palm companies have built new flood control dams during or shortly before our field visits (2012–2017; Fig. 2). According to a representative of one of these companies, the need for additional water infrastructure arose because of an observed increase in flood frequency. In accordance with the villagers' observations, he associated this increase with upstream deforestation activities. Consequently, the company constructed additional drainage channels and flood control dams, and made use of water pumps to mitigate flood impacts on their plantations. According to the villagers, such infrastructure redistributes floodwaters locally, increasing the frequency and intensity of flood events on their own plantations (see Table 2: Q9 and Q10). In two villages, village authorities complained that they had not been informed about nor involved in the planning of the flood control dams. In consequence, villagers tried to protest against the building of such dams by writing letters to local authorities or organizing roadblocks. Yet, they were not successful in stopping such constructions at the time of research.

Fig. 2: Recently built flood control dam on an agro-industrial oil palm plantation.:

4.2. Quantitative environmental measurements

River water level

To interrogate water level data for the observed changes in the frequency and intensity of flood events we used the nonparametric Mann-Kendall trend analysis and linear regression. On a monthly basis, the Tembesi River at Pauh hydrological station had a mean water level of 6.07 m (± 1.29 m standard deviation) over the period 1997–2016 (Table A2.1). On average, mean water levels are 6.88 (± 1.42 m) in the wet season (October–May), which is 1.9 m (± 1.35 m) higher compared to the dry season (June–September; Table A2.1). Our trend analysis showed a small but significant increase of annual mean river water levels by 0.10 m yr^{-1} over the 20-year study period (Mann-Kendall $\tau = 0.18$, $p < 0.001$). This observed increase in mean river water levels was more pronounced in the wet season, with 0.12 m yr^{-1} (Mann-Kendall $\tau = 0.29$, $p < 0.001$) compared to the dry season, with a respective increase of 0.06 m yr^{-1} (Mann-Kendall $\tau = 0.14$, $p < 0.05$; Table A2.1). Extreme water levels of > 11 m, as an indicator for flood events, occur almost exclusively during the wet season (92%) in coherence with intense precipitation ($R^2 = 0.99$; Fig. 3c, Table A2.2). According to the Mann-Kendall test, the frequency and duration of such extreme river water levels has increased significantly over the study period (Mann-Kendall $\tau = 0.45$, $p < 0.01$; Table A2.2).

Because villagers reported that flood events today would occur even after only short rainfall events, we investigated changes in the frequency and intensity of flash floods as well as in the average water level rise. Water levels during a flash flood event (a rapid increase in river water level > 1 m between two consecutive days) increase on average by 1.59 m (± 0.67 m) during such events. The frequency and intensity of such flash flood events remained relatively constant over the study period (Mann-Kendall $\tau = 0.04$, $p = 0.36$). However, our analysis of the average water level rise of the Tembesi between two consecutive days (Table A2.3) indicates weak evidence for an increase in the fluctuation of river water levels (Mann-Kendall $\tau = 0.16$, $p < 0.01$).

To interrogate a changing predictability of flood events we analyzed seasonal patterns of extreme water levels, mean river water levels and flash flood events. However, we did not find any significant shift in the seasonal patterns of mean river water levels (Table A2.1) or flash floods and the increase of extreme water levels was only significant ($p < 0.05$) in the wet season, i.e., in January and November (Fig. 3d, Table A2.2).

The analyses of river water levels show that flooding is an important component of the Tembesi River hydrology. Therefore, we used a digital elevation model and the river network to generate a flood risk map (see Appendix 3). We found that in the case of a 100-year flood event, about 408 km^2 of land adjacent to local rivers would be flooded, with strong negative impacts on local infrastructure, agriculture and villages.

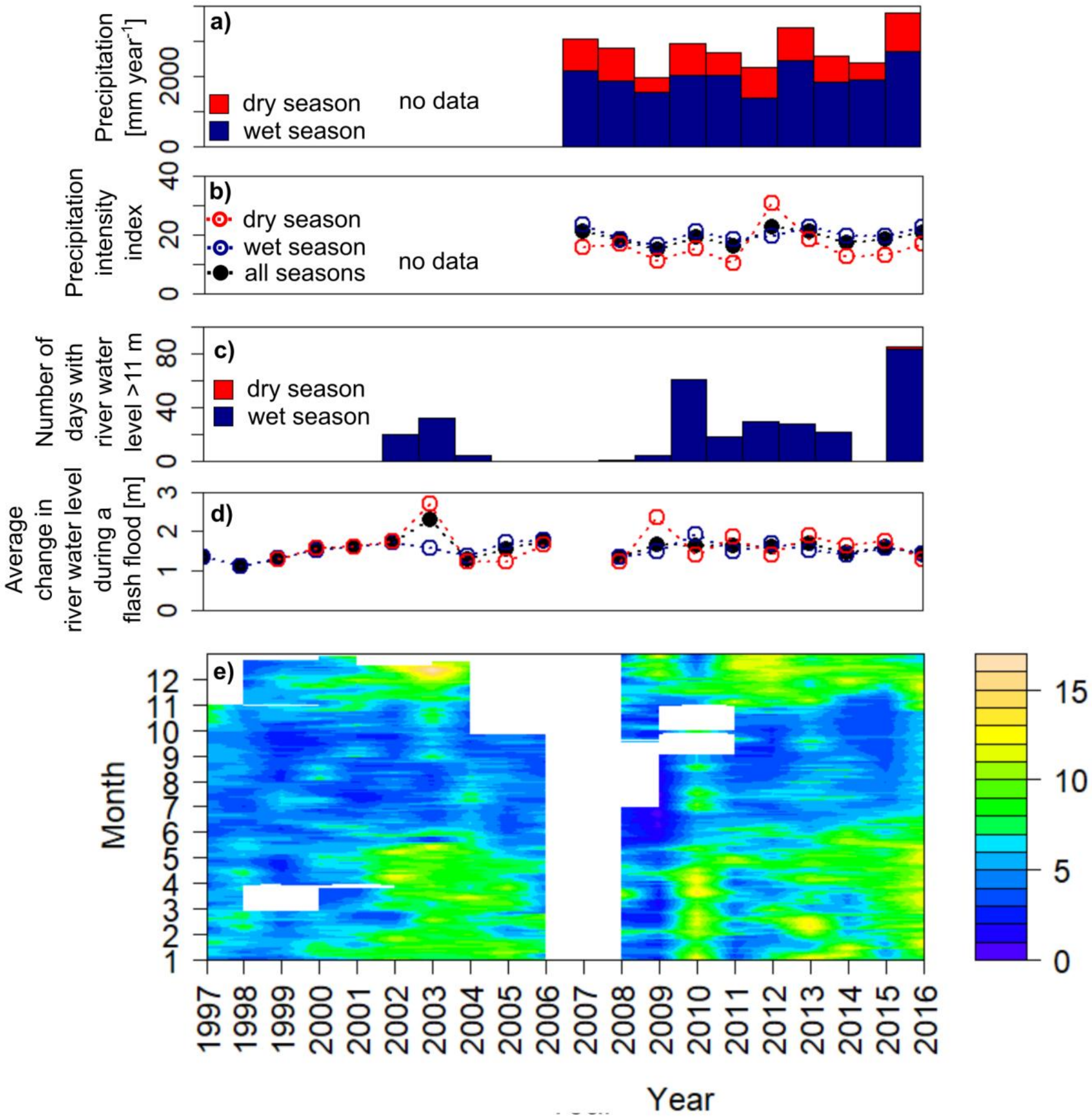

Fig. 3: Accumulated precipitation (a) and mean precipitation intensity index (b) at Pauh meteorological station during the period 2007 to 2016. Days within one year with water level of Tembesi River above 11 m (c), average change in river water level of the Tembesi River during a flash flood event (d), and fingerprint map of Tembesi River water level at Pauh hydrological station (e) during the period 1997 to 2016 (no data for 2007).

Precipitation

Precipitation patterns at Pauh meteorological station are well reflected in the behavior of the Tembesi River water levels recorded at Pauh hydrological station. However, precipitation patterns from Jambi airport do not generally explain the water level characteristics at Pauh hydrological station, probably because of the station being located outside of the Tembesi watershed. At both meteorological stations, monthly accumulated precipitation displays large seasonal and annual fluctuations (Fig. 3a, Table A4.1, Table A4.3). At Pauh, November and December show the highest rates of precipitation and the strongest precipitation intensity (Table A4.1 and Table A4.2), which is also reflected in the annual peak of river water levels during those two months (Fig. 3e). At Jambi, where we have a longer record of precipitation measurements, April shows the highest accumulated precipitation and precipitation intensity is strongest in March (Table A4.3 and Table A4.4).

At both meteorological stations, we found no clear trend in total accumulated precipitation and no shift in the distribution of precipitation between the wet and the dry season (Table A4.1–A4.4). At Pauh however, we found a clear trend toward higher precipitation at the end of the wet season in May (Mann-Kendall $\tau = 0.60$, $p < 0.05$) and at the beginning of the wet season in November (Mann-Kendall $\tau = 0.56$, $p < 0.05$; Table A4.1), which, for the latter, is in agreement with our findings of increased river water levels at the beginning of the wet season (Table A2.2).

Land use change

In 1990, about half of the Tembesi watershed was covered with forest areas. Between 1990 and 2013, this forest area decreased by 25%, from 6835 km^2 to 5108 km^2. Today, most of the remaining forest area is located in the upstream, mountainous area of the watershed (Fig. 1; for an accuracy assessment of the land use classes see Table A5.1). The forest loss in the watershed can mainly be explained by an increase in plantation area as well as in bush/bare land (Fig. 4). From 1990 to 2013 the area cultivated with oil palm plantations expanded by 54%, from 939 km^2 to 1451 km^2. Rubber plantations increased by 25%, from 2714 km^2 to 3404 km^2. The area of bush or bare land increased by 59%, from 597 km^2 to 947 km^2. In consequence, in 2013, oil palm plantations covered 11%, and rubber plantations 25% of the Tembesi watershed. The area of mixed agricultural land has remained almost the same over the same period, covering 15% of the watershed's area in 1990 and 16% in 2013.

According to the wetland map we created, wetland areas constitute 8.35% of the Tembesi watershed (1116 km^2). In 1990, about one-third of these wetlands were covered with forests, while 54% of the wetlands were used for different types of agriculture (Fig. 4). The proportionate loss of forest cover in wetlands was even greater than in the whole watershed. From 1990 to 2013, forest areas in the watershed's wetlands decreased by 73%, from 347 km^2 to 93 km^2. This implies that 15% of the total forest loss between 1990 and 2013 in the Tembesi watershed occurred in wetland areas although these comprise only 8.35% of the whole watershed. The converted forest area was almost exclusively planted with oil palm plantations, which almost doubled in area from 1990 to 2013, from 244 km^2 to 479 km^2, respectively. In fact, 33% of all newly developed oil palm plantations in the Tembesi watershed have been established in wetland areas.

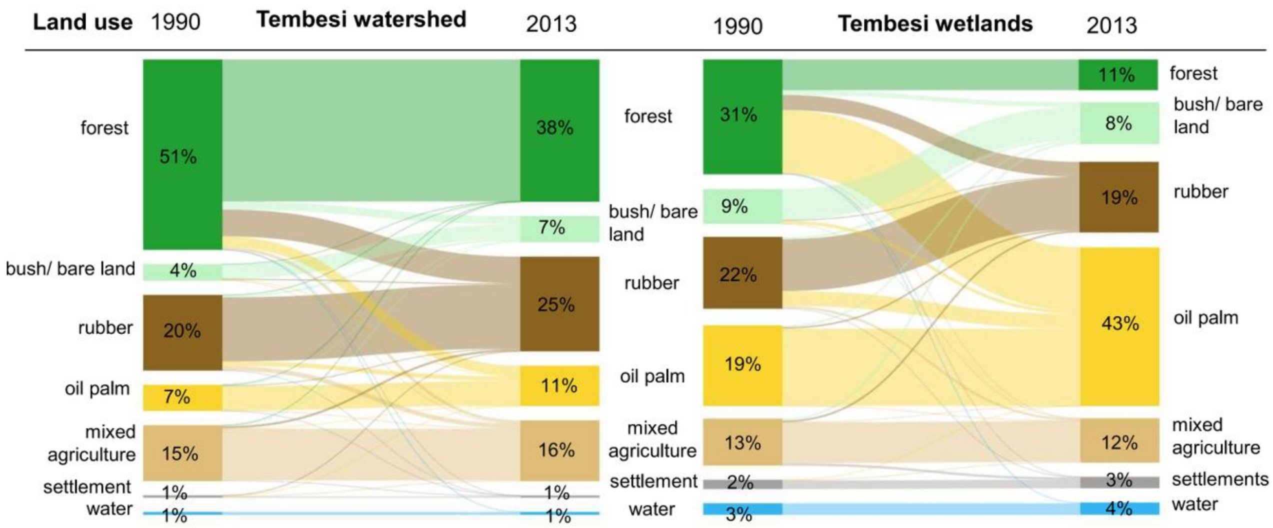

Fig. 4: Land use change in the Tembesi watershed and its wetland areas between 1990 and 2013 (based on land use data by Melati 2017). Total area: Tembesi watershed 13,370 km², wetlands 1167 km².

Soil bulk density and water infiltration capacity

Bulk densities of rubber and oil palm plantations in the topsoil (0–10 cm) were 1.3-fold higher (1.14 ± 0.05 and 1.13 ± 0.05 g cm^{-3}, mean ± standard error) than at the reference rainforest sites (Fig. 5). In contrast to the topsoil, bulk densities in deeper soil layers (30–50 cm) showed similar values across all land use systems (1.37 ± 0.03 g cm^{-3}).

Saturated soil hydraulic conductivity (K_{fs}) in an oil palm monoculture plantation (6.5 ± 1.7 cm h^{-1}, n = 4) was three times lower than in the oil palm biodiversity experiment (22.6 ± 2.6 cm h^{-1}, n = 33; Fig. 6), suggesting higher surface runoff in the former. Additional measurements with a conventional double-ring infiltrometer in another oil palm plantation gave lower K_{fs} (0.7 ± 0.2 cm h^{-1}, n = 6).

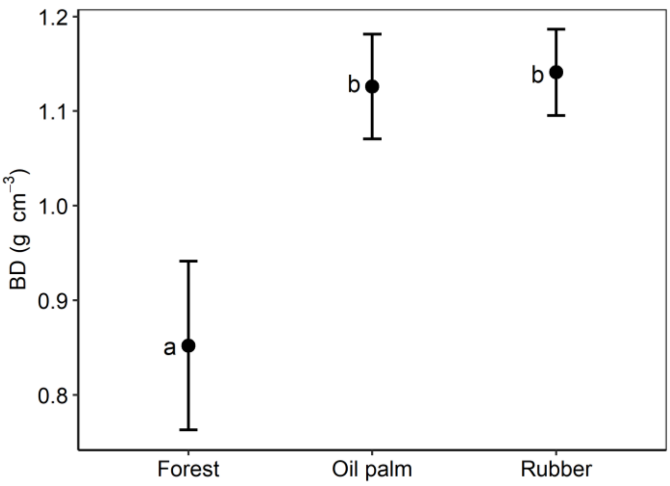

Fig. 5: Topsoil (0–10 cm) bulk densities (BD, g cm-³) at 10 sites each in forest, rubber, and oil palm plantations (sites described in Drescher et al. 2016). The dots represent means and the error bars the according standard errors. Different letters represent significant differences among groups (Kruskal-Wallis test, p < 0.05).

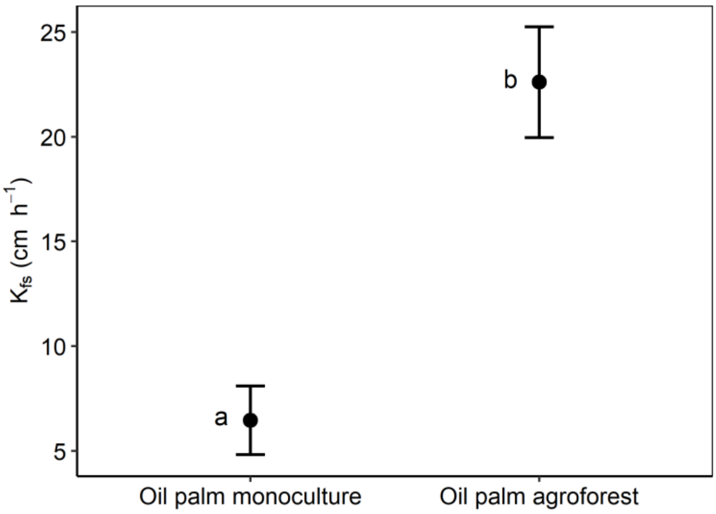

Fig. 5: Saturated soil hydraulic conductivity (Kfs, cm h-1) in oil palm monoculture control plots (n = 4) and in plots within the oil palm biodiversity experiment (n = 33; sites described in Teuscher et al. 2016). The dots represent means and the error bars the according standard errors. Different letters represent significant differences among groups (Kruskal-Wallis test, p < 0.05).

Groundwater levels

Groundwater table (GWT) measurements in riparian areas showed that the mean GWT in the rubber and oil palm plantations is lower than in the forest reference sites (Fig. 7). On average, the GWT during the period July 2017 to April 2019 was 0.55 m (± 0.27 m) below the soil surface in the forests, and 1.03 m (± 0.39 m) and 1.24 m (±0.50 m) below the soil surface in the rubber and oil palm plantations, respectively. In addition, GWTs in the plantations (rubber and oil palm) showed higher amplitudes compared to the GWT in the forests (Fig. 7b). After a rainfall event, the GWT in the plantations can increase up to 1.5 m within a few hours while in the forests, the increase in the GWT after a rainfall event is less pronounced, with a maximum of ~0.5 m (Fig. 7). Although the mean GWT in the plantations is lower than in the forests, GWTs in the plantations regularly exceed the respective GWT of the forests. This indicates that after a rainfall event, the rubber and oil palm plantations are more prone to flooding than the forests.

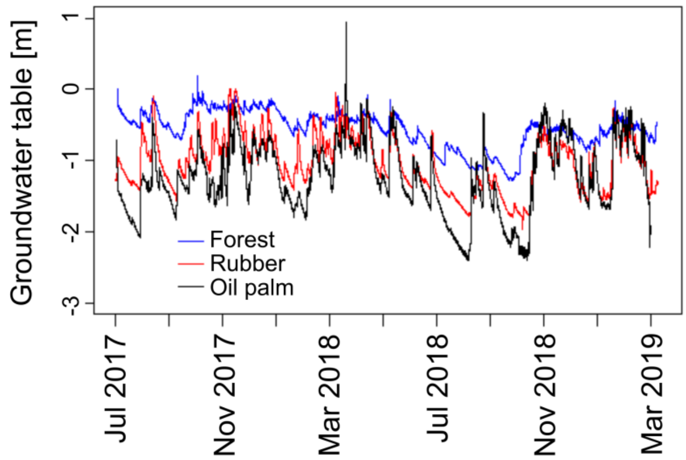

Fig. 7: Development of average groundwater table at forest (0.55 ± 0.27 m, n = 4), rubber (1.03 ± 0.39 m, n = 4), and oil palm (1.24 ± 0.50 m, n = 4) riparian locations during the period July 2017 to April 2019.

5. Discussion: integrating insights from local ecological knowledge and scientific measurements

5.1. Comparing villagers' observation of changing flooding regimes with stream flow data

Villagers interviewed for this study reported an increase in flood frequency and intensity following extensive land use change toward rubber and oil palm monoculture plantations during the past two decades. These findings are in line with the observed increase in frequency and duration of extreme river water levels (> 11 m; $\tau = 0.45$). Government reports from Jambi Province provide some additional support to these measurements as they discuss flooding as an increasing environmental problem across Jambi Province and beyond the Tembesi watershed (Minister of Public Works 2012, Batanghari Watershed Office 2016, Jambi Provincial Government 2016). They are also in line with other studies across Indonesia, where local people associated increases in flood frequency and intensity with land use change from forests to oil palm plantations and other types of land use (Obidzinski et al. 2012, Larsen et al. 2014, Wells et al. 2016, Kelley and Prabowo 2019). Our findings further correspond with studies showing increases in streamflow (Adnan and Atkinson 2011) and in the number of days flooded (Tan-Soo et al. 2016), which is associated with land use conversion to rubber and oil palm plantations.

The interviewed villagers further reported that following land use conversion, flood events have become difficult to predict because water levels today rise faster after rainfall events and the occurrence of flooding has partly shifted in seasonality. A decreasing predictability of flood events following land conversion has also been a common observation by villagers in different areas across Indonesia (Leimona et al. 2015, Kelley and Prabowo 2019). Our water level data, however, showed no substantial evidence supporting these observations by local villagers. Flash flood events of the Tembesi River have not changed in frequency, intensity, or seasonality over time and significant increases in extreme water levels were only found during the wet season. Only the slight increase in average water level rise (τ = 0.16) provides a small indication supporting villagers' observation of larger fluctuations in water levels. Because discharge data is only available from one hydrological station in the Tembesi watershed, our data, therefore, provide very selective insights into hydrological processes at the watershed scale. As the catchment area upstream of our hydrological station covers over 10,000 km^2, flash flood events in smaller subcatchments may not result in significantly higher water levels of the Tembesi River. In general, it has been found that the impacts of land use change on river water levels may be larger in smaller watersheds (Bruijnzeel 1990, van Dijk et al. 2009). Farmers who own plantations adjacent to smaller streams, e.g., the Air Hitam River, may thus observe larger changes in water levels than are reflected in the water levels of the Tembesi River. Indications supporting this hypothesis can be found in our measurements of groundwater tables, which show rapidly increasing water levels in rubber and oil palm plantations after rainfall events.

5.2. Potential contributions of local climate change to changing flooding regimes

Several interview partners reported seasonal shifts in local rainfall patterns, which could thus potentially provide an explanation for the villagers' reports that flood events have become difficult to predict. Our analysis of precipitation data may partly explain the villagers' complaints as it indicates a clear shift in the seasonal distribution of precipitation toward higher precipitation rates at the end of the wet season in May. Similar accounts about increasingly unpredictable rainfall patterns were reported from farmers across different regions in Jambi Province (Merten et al. 2016, Martens 2017, Rödel 2018). Considering this widespread observation, the measured changes in the seasonal distribution of precipitation appear relatively small. Further data from different meteorological stations across Jambi Province would thus be needed to discuss the villagers' observation of changing seasonal rainfall patterns in more detail.

Changes in rainfall patterns could further provide an explanation for the measured increase in the average water levels of the Tembesi River. However, our analysis of precipitation data at Pauh and Jambi airport meteorological station showed that the total amount of precipitation as well as the overall precipitation intensity has remained relatively constant over the past decades. Our precipitation data available for the Tembesi watershed, however, only covers the lowland areas. Hence, we cannot rule out changes in precipitation patterns in the highland regions of the Tembesi River watershed, which may have contributed to the observed increase in water levels.

Deforestation can modify rainfall patterns because of vegetation-atmosphere interactions at various spatial scales (Lawrence and Vandecar 2015, Spracklen et al. 2018). Large-scale forest conversion, as in the Tembesi watershed, typically leads to a reduction of rainfall and therefore river discharge (Lawrence and Vandecar 2015). However, this might be different in the case of forest conversion to oil palm plantations in which evapotranspiration remains relatively high (Röll et al. 2019). On the other hand, deforestation in heterogeneous landscapes such as the Tembesi watershed may increase rainfall over deforested areas and thereby increase both river discharge and river water levels (Lawrence and Vandecar 2015). Moreover, global climate change is expected to increase both total annual precipitation and extreme precipitation in Southeast Asia (Ge et al. 2019). Although such trends are not yet identifiable in our precipitation data, such developments could further increase both river discharge and river water levels in the future. Long-term climate records and a dense network of meteorological stations are therefore indispensable for studying the current and future linkages between precipitation and river discharge.

5.3. Potential contributions of land use change to changing flooding regimes

Evidence for altered hydraulic soil properties after forest conversion

The villagers interviewed in this study reported that flooding regimes started to change after vast forest areas had been converted to rubber and oil palm plantations. Our land use change analysis, together with our measurements of soil properties and groundwater levels in different land use systems, provide indications that the large-scale land use change might have contributed to changes in the ecohydrological functioning of the Tembesi watershed. High soil compaction in monoculture rubber and oil palm land use systems is in line with results of other studies in the tropics, showing that forest conversion and associated soil compaction leads to 1.2- to 1.3-fold increases in topsoil bulk density (Don et al. 2011, Li et al. 2012). Higher bulk densities in monoculture plantations than in forests are likely the result of severe soil erosion and changes in soil properties (Guillaume et al. 2015, 2016), e.g., compaction caused by heavy machinery during deforestation or subsequent harvesting operations. Such increases in soil compaction may go along with significantly lower saturated hydraulic conductivities (K_{fs}; Pachepsky and Park 2015). Our measurements indicate that subsoil bulk densities (30–50 cm) remain unchanged across the different land use systems, which corresponds with a previous study from the region (de Blécourt et al. 2013). However, it has been suggested that increases in topsoil bulk density alone are sufficient to strongly reduce K_{fs} in soils of the humid tropics (Hassler et al. 2011). In a meta-analysis, Pachepsky and Park (2015) suggested that topsoil bulk densities of around 1.36 g cm^{-3} form a critical threshold, beyond which they have altered hydraulic properties such as hydraulic conductivity, permeability, and porosity due to soil compaction. In our study, more than 30% of the assessed oil palm and rubber plantations cross this threshold. Such changes in hydraulic soil properties are further supported by our measurements of saturated hydraulic conductivity (K_{fs}). Our very low K_{fs} values coincide with a previous study in the region, where soil water infiltration in oil palm monocultures (3 cm h^{-1}) was reported to be 60% lower than in rubber plantations (7.8 cm h^{-1}) and more than 15-times lower than in reference rainforests (47 cm h^{-1}; Tarigan et al. 2018). These results, as well as ours, thus point to very low K_{fs} in conventionally managed oil palm monocultures, which is most likely related to the described soil compaction. These observations are in agreement with the villager’s observation that soils in plantations do not effectively absorb or retain rainwater.

The type of vegetation in riparian areas is critical for infiltration capacity, overland flow, and groundwater recharge (Alvarenga et al. 2017). Our groundwater table (GWT) analysis in riparian areas showed that rubber and oil palm plantations have lower GWTs compared to forests. This might be related to the relatively high soil compaction and the low water infiltration capacities in monoculture plantations, as mentioned above. Higher amplitudes of GWT in oil palm and rubber plantations compared to forests indicate a loss of buffer functions such as flood moderation, groundwater recharge, and soil water storage in the plantations. Hence, our measurements of bulk density, water infiltration, and groundwater tables point to substantial increases in surface runoff after precipitation, which could potentially increase flood frequency and intensity (Bruijnzeel 2004). This line of argument is supported by a previous study in the region, which modeled large increases in surface runoff with an increasing share of rubber and oil palm plantations in a given watershed (Tarigan et al. 2018). Although our water level data from the Tembesi River did not reflect villagers' observation that rainfall nowadays accumulates faster in local rivers than they remember from the past, our measurements of hydraulic soil properties and groundwater levels provide substantial indications that support this observation.

Our analysis of soil water infiltration in oil palm plantations where biodiversity enrichment has been carried out, however, suggests that tree planting and regeneration of natural vegetation could partially restore the very low infiltration capacity. Five years after the establishment of the experiment, average K_{fs} in the enriched oil palm plantation was at least three-times higher than in oil palm monocultures. These findings are consistent with a meta-analysis across the tropics that reports on average three-fold increases of water infiltration capacity after afforestation or tree planting in agricultural fields (Ilstedt et al. 2007).

Our measurements thus provide several indications that forest conversion and subsequent alteration of soil properties may explain the measured increase in the Tembesi's water levels. However, especially in larger catchments, the interaction of land use and ecosystem processes increases in its complexity and causes with increasing catchment area (Bruijnzeel 1990, van Dijk et al. 2009). Studies from several river catchments in the tropics have shown that other processes related to land use change and subsequent changes in soil properties, e.g., sedimentation, road construction, missing buffer zones, or illegal gold mining have the potential to further increase river water levels (Allan 2004, Ziegler et al. 2006, Wantzen and Mol 2013, Carlson et al. 2014, Luke et al. 2017). These above-mentioned processes are also found in the Tembesi catchment area and, with the relatively large extent of the river, this myriad of complex land use changes and related interactions may therefore further contribute to the observed increases in river water level.

Increases in the Tembesi river water levels in both the dry and rainy seasons might be explained by the complexity of interacting ecosystem processes. In the case of reduced water infiltration capacity of soils coupled with high (evapo)transpiration rates in oil palm monoculture plantations (Manoli et al. 2018), a reduction of water levels in rivers during the dry season might be expected (Bruijnzeel 1990). Indications for such changes were suggested for oil-palm-dominated landscapes by Merten et al. (2016). Rubber plantations, on the other hand, exhibit lower (evapo)transpiration rates in smallholder-dominated cultivation systems in Jambi (Röll et al. 2019). Therefore, the impact of land conversion on the river water level in larger watersheds with mixed land use systems may be less discernible.

Potential contributions of wetland conversion and water infrastructure to changing flooding regimes

Despite their important ecological role (Bhowmik 2020), wetlands have often been described and treated as wastelands and hence converted into other land use types (Barbier et al. 1997). Our land use change analysis indicates a much higher rate of forest conversion in wetland areas compared to well-drained sites. According to interview data, this land use change can be explained by both governmentally planned plantation establishment as well as market-driven expansion of oil palm plantation into marginal areas. This trend of oil palm plantations expanding into wetlands areas has also been reported in other regions across Indonesia and Malaysia (Abram et al. 2014, Guillaume et al. 2016, Schoneveld et al. 2019).

Because of plantation expansion into wetland areas, but also because of the reported increases in flood frequency and intensity, flood control infrastructure such as dams and drainage channels have recently been installed across all our case study villages. Although we cannot quantify to what extent such infrastructure has contributed to an alteration of flooding regimes at the landscape level, our interview partners reported that the construction of flood control dams, water pumps, and drainage gates contribute to a redistribution of floodwaters at the local scale. Such developments are considered particularly sensitive because government representatives during interviews confirmed that the construction of water infrastructure often happens without legal notice. Accordingly, the first author observed the emergence of social conflicts.

Our interview data as well as observations in the field show that most of the studied wetland areas were managed by or with the support of private companies, external investors, or more well-off farmers. Likewise, Schoneveld et al. (2019) and Kelley and Prabowo (2019) show that plantation development on peat soils and flood prone riverbanks in Indonesia was mainly realized by more well-off farmers, political elites, and private companies that adopted more industrialized land use operations. This concentration of companies and local elites in wetland areas, together with the already mentioned conflicts over water infrastructure, creates a risk of an increasingly unequal distribution of flood damage. Surprisingly, to our knowledge, no study linking oil palm expansion to increasing flood frequency and intensity has yet paid attention to the role of infrastructure in changing flooding regimes or to the associated social impacts.

The large-scale expansion of plantations into wetland areas may also have contributed to changing flooding regimes by reducing the ecohydrological functioning of these ecosystems. Review studies suggest that lowland wetlands may substantially reduce or delay flood events (Bullock and Acreman 2003, Acreman and Holden 2013, Mitsch and Gosselink 2015). Anthropogenic activity in wetlands strongly affects local river systems because of frequent lateral water exchange between rivers and wetlands (Junk et al. 1989, Junk and Wantzen 2004). Although no data on wetland hydrology were available for the Tembesi watershed, the drainage and burning of large areas of peatlands in the watershed (Uryu et al. 2010, NASA FIRMS 2019) is particularly indicative of a degradation of local ecohydrological functions. Drainage and burning of peat soils is known to alter their physical properties, resulting in peat subsidence and compaction, thus reducing the water absorption of peat swamps (Andriesse 1988, Page et al. 2006, Wösten et al. 2008, Evers et al. 2017). Moreover, the subsidence of peat soils is considered to progressively lengthen periods of inundation (Wösten et al. 2006, Hooijer et al. 2015, Sumarga et al. 2016).

6. Conclusion and final reflections

Our analysis showed that the observed and measured increase in flood frequency and intensity within the Tembesi River catchment area is most likely driven by land use change from forests to monoculture plantations. This development appears to be related to soil compaction, decreasing water infiltration rates, and, therefore, higher surface runoff. It might further be aggravated by the expansion of oil palm plantations into wetland areas and the subsequent construction of drainage and flood control infrastructure.

Our study illustrates how interrogating local ecological knowledge and integrating it with multidisciplinary scientific measurements can drive forward problem-centered research on the linkage between land use change and flooding. This study benefited from data integration in three important ways. First, local people's reports of changes in flooding regimes following land conversion, draw our attention to a problem of environmental change previously not accounted for by our research project. We thus build upon local people's ecological knowledge to then interrogate datasets from different disciplines, whether they provide indications confirming villagers' observations and evaluations or not. None of the data analyzed were initially collected for the purposes of studying flooding, and hydrological data provided by the provincial government in Jambi remain scarce and often incomplete. Despite this, the analyzed data provided substantial indications that support people's claims that land use change alters local flooding regimes. The villagers' observations and evaluations matched well with our measurements of extreme river water levels and altered hydraulic soil properties in monoculture plantations. In data-poor regions, such an integration of multidisciplinary datasets may thus help us to gain insights into socially relevant research topics that are otherwise neglected.

Second, villagers' observations of changing flooding regimes, such as increases in the frequency of flood events or more rapidly rising water levels after rainfall, also helped us to define what indicators to look for in local water level data. As a result, our problem-based research approach pointed out significant gaps in our data, which, by analyzing water level data alone, might not have appeared as a gap at all. Although the predictability of flood events appears to be a major concern for local farmers in Jambi, our analyzed data does not mirror seasonal shifts in flood events and only small shifts in seasonal rainfall. Reports of shifting seasonal rainfall patterns, however, have been common across different areas in Jambi Province, and a decreasing predictability of floods has also been reported in other areas with rapid land use change (Leimona et al. 2015, Kelley and Prabowo 2019). This mismatch points to a need for more fine-scaled spatial and temporal monitoring of water levels and precipitation in the area to improve our understanding of the complex linkages between river discharge, land use change, and climate change.

Finally, the integration of local ecological knowledge draws our attention to the multiplicity of processes that influence the occurrence of flooding. Our study reveals that the construction of drainage or flood control infrastructure has aggravated changes in local flooding regimes, thus generating new social conflicts. Newly installed infrastructure was observed to redistribute floodwaters at the local level and thus to play a crucial role in the mediation of the social impacts of flooding. Surprisingly, the role of technical infrastructure in mediating water flows has received little scientific attention in studies connecting land use change with changing flooding regimes. More studies are needed to assess and monitor the hydrological impacts of such water management practices, as well as the social and economic relations that shape these practices.

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Author Contributions

JM, CS, MD, HF, LF, DH, NH, AK, EP designed the study. JM, CS, NH, FO, AH, JK, DCZ contributed data to the manuscript. JM, CS, NH, AR, EP performed data analysis and interpretation. JM and CS prepared the manuscript. NH, AR, EP contributed to writing the manuscript. JM, CS critically revised the manuscript. All authors discussed the results and commented on the manuscript.

CHAPTER IV:

From rising water to floods: disentangling the production of flooding as a hazard in Sumatra, Indonesia

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Highlights:

- Risk research must increase our understanding of what is considered a hazard
- Hazards (incl. floods) are the product of past and present socionatural relations
- Relational approaches to risk and natural resources help to study hazards
- In Jambi, Sumatra, land use change alters the materiality and meaning of flooding
- The prioritization of dry land for plantation development is a main driver of this

Abstract

In Jambi province, Sumatra, Indonesia, flooding is a recurrent rainy season phenomenon. Historically considered manageable, recent political economic developments have changed this. Today, flooding is an environmental hazard and a threat to people's livelihoods and health. Based on qualitative research and literature that has developed relational approaches to risk and water, we investigate past and present hydrosocial relations in Jambi province and reconstruct the changing meaning of flooding. We suggest that flooding as a hazard in Jambi was produced through the introduction of the plantation business to the area and its prioritization of dry land for agro-industrial development. This development altered the materiality of water flows, reconfigured power relations and changed the socio-cultural dimensions of flooding. Together, these changes have led to a separation of flooding from its original social and geographic realm, producing new risks and vulnerabilities. The paper adds insights into the material and symbolic dimensions that influence how environmental processes come to be imagined, controlled and contested. It shows how tracing the socionatural production of hazards may help explain the increasingly systemic nature of risks and provide insights into the wider social meaning of environmental risks.

Keywords: *hydrosocial relations; hazards; risk; vulnerability; land use change; political ecology; Indonesia*

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1. Introduction

In Jambi province, Sumatra, Indonesia, rivers overflow their banks during the rainy season. People living along the rivers had adapted to this, building daily practices and cultural identity in a close relationship with rivers and floods. Extensive cultivation of riparian floodplains, agroforestry and fishing constituted a mainstay of the local economy. In the local dialect, people referred to floods as "rising water" (*air naik*) or "deep water" (*air dalam*). Neither term entailed an immediate threat to their lives and livelihoods. In the 1980s, Jambi province went through a national economic development program. Plantations were established transforming land cover and use on a large scale subsequently attracting migrants and private investments to the Province. This changed the relationship between people, rivers and floods. Today, flooding is more frequently discussed as a threat to people's livelihoods and people use the official Indonesian word for flooding, "*banjir*", more often. This term carries the added connotation of the risk of disaster. As this paper will show, flooding in Jambi has transformed from an expected seasonal phenomenon into a hazardous event.

Hazards are environmental processes and events potentially harmful[13] and, in combination with human vulnerability, they produce the risk of disaster (Wisner et al., 2012). Yet, the study of interactions and feedback mechanisms between environmental and social processes in the constitution of risk remains a key challenge in risk research as this remains divided into hazard-centered approaches and vulnerability studies (Lele, 2009, Wisner et al., 2012, Di Baldassare et al., 2014, Ribot, 2014). While the former locate risk in the environmental hazard and focus their study on biophysical changes therein, the latter locate risk in social structures and inequalities and focus their analysis on socio-economic and political causes of human vulnerability to hazards (Rebotier, 2012, Ribot, 2014).

Relational approaches to risk have contributed to overcoming this analytical divide. They have conceptualized environmental risk as a socionatural production, or as a situated production arising from specific society-nature relations that are deeply embedded in local geography, environmental changes, history and culture (Rebotier, 2012). Such an understanding has contributed to three major theoretical advancements. First, it has enabled a more dynamic understanding of risk and vulnerability, rejecting static risk assessments and recognizing risk as being constantly in production (Collins, 2009, Simon, 2014). Second, it has led to the recognition of risk and vulnerability existing both as a material condition and as a discursive construct (Jasanoff 1999, Simon & Dooling, 2013). Risk studies have thereby expounded how different representations of risk and vulnerability – e.g. discourses about who is at risk and why – are socially contested. Third, it has shown how hegemonic risk discourses contribute to the production of highly uneven landscapes of risk and vulnerability through shaping risk prevention, assessment and response policies (Collins, 2009, Rebotier, 2012, Simon & Dooling, 2013, Neale et al., 2016).

Few studies have used these insights to interrogate the socionatural production of environmental hazards, questioning how normal environmental processes or natural resources turn into threatening hazards (Walker et al., 2011, Ribot, 2014, Jones et al., 2014, Langill & Abizaid, 2019). In this paper, we

[13] The term hazard is inconsistently conceptualized in the literature and sometimes interchangeably used with the term disaster, as an event resulting in loss and damage (Smith 2013, Wescoat 2015).

explore how a physical event, rising waters, becomes a hazardous flood. We show that hazards are not purely biophysical phenomena that simply exist, but also, like risks and vulnerability, they are the outcome of socionatural relations. Attached with meaning and values, these, in combination with biophysical and material aspects, constitute, we argue, something as a hazard.

To illustrate this, we draw on literature on relational approaches to natural resources and water from political ecology and anthropology. These bodies of literature have provided rich accounts of how flooding is best conceptualized as a socionatural production that is shaped through the dialectic relationship between water and society (Swyngedouw, 1999, Linton & Budds, 2014). This allows us to explore the ontological multiplicity of water (Linton, 2010, Hamlin, 2010, Boelens, 2014), the specific materialities of water that shape social relations in Jambi (Bakker, 2003, Barnes, 2014), the socio-cultural meaning of rivers and flooding (Baviskar, 2003, Acharya, 2015), and the power relations embedded in local water flows (Swyngedouw, 2004, Budds, 2009, Swyngedouw 2015, Boelens, 2014). The historical socionatural production of water-related hazards such as floods or water scarcity is prominent in such research (e.g. Mehta, 2007, Budds, 2009, Fernandez, 2014, King et al., 2019).

This paper begins by reviewing recent theoretical advancements in hydrosocial research. We focus on how this literature helps explain the production of flooding as a hazard. We then present our methods before turning to our results. The results analyze the socionatural production of flooding as a hazard over time using the case study of Jambi province. Following Ribot (2014: 680), we ask what makes a hazard a hazard, or what turned "deep water" into "flood" in Jambi? We investigate past material and discursive hydrosocial relations that shaped an understanding of flooding as a normal seasonal phenomenon. We then trace how this was reshaped through political-economic transformations in Jambi over the last three decades. Particular attention is paid to how agro-industrial plantation systems transformed Jambi's landscape and seasonal water flows as well as how different actors engage discursively and materially with flooding. In the discussion, we use our empirical insights to discuss what conditions and processes have enabled the recent production of flooding as a hazard. We further illustrate how studying the historical production of a hazard can further our understanding of the production and meaning of hazards and risks. We round off the paper with a conclusion.

2. The socionatural production of flooding as a hazard

During the past two decades, there has been an increasing recognition of how water and society shape each other in a dialectical process of mutual adjustment (Linton & Budds 2014). In his seminal work on the production of the Spanish waterscape, Swyngedouw (1999, 2004, 2015) showed how water flows in Spain are deeply embedded in and infused by social power relations. He thus conceptualized water as a socionatural hybrid produced in a 'hydrosocial cycle' of material processes, cultural practices, discursive representations and social power relations (Swyngedouw, 2004, see also Linton & Budds, 2014).

Using the hydrosocial cycle as an analytical framework has helped researchers to identify the assemblage of historical, hydrological, political and technological circumstances that produce specific instances of water, and to question how these configure social relations (Linton & Budds, 2014). Thereby, this body of literature has convincingly revealed how, for example, social inequalities and injustices become produced and sustained through water and the role of water's particular materiality in shaping social relations (Budds, 2008, Debanné, 2013, Wilson, 2014, Barnes, 2014). It has further shed light on the varied socio-cultural dimensions and meanings of water (Baviskar, 2003, Boelens, 2014, Acharya, 2015).

Water's particular physical nature connects places and people across political, legislative and socio-cultural spheres, interacting with different actors and power relations (Krause, 2016). It has an inherently relational character. Water is also both beneficial and harmful. It is essential for human survival, an economic resource, a source of personal hygiene, a disruptive force, or a carrier of pathogens - to mention just a few attributes (Boomgard, 2007). Through this multiple and variable character, water actively shaped histories and geographies (Bear and Bull, 2011). The temporality of water through its' seasonal and tidal rhythms have for example been shown to shape and change social life over time (Harris, 1998, Jones, 2011, Camargo, 2017). Indeed, the consonance or dissonance of temporal relations between social and natural rhythms may be a deciding factor in determining whether a water flow is productive or disruptive (Jones, 2011). Whitt (2018) showed, for example, how water risks in Bolivia were produced as existing hydrosocial relations fell apart, producing a "cyclic dissonance" between the cycles of water and people's management of it.

Water is thus to some extent "what we make of it" (Linton, 2010: 3). Definitions of flooding, for example, are embedded in people's daily experience, practices and ideas and expectations of where water belongs (Walker et al., 2011). Walker et al. (2011: 2306) show how in Hull, England, water only becomes floodwater when it crosses a boundary of "spatially constituted normality" when it moves "out of place". They thus assert a necessary "abnormal" quality to flooding. But the definition of abnormality is geographically determined, fluid, open, multiple, value laden and contested in terms of when water is considered to be "out of place" and who gets to determine this (Walker et al., 2011). Defining what water is and where it belongs constitutes an important part of Linton's (2010) work on the 'modern' understanding of water. Linton shows how water and modern ideas about it were shaped during the enlightenment where water, abstracted as H2O, was ontologically separated from its social realm. Being able to control "natural" water flows became a manifestation and goal of modernization with flooding constituting a hazardous disorder that interrupts social and economic life (Oliver-Smith, 2002, Linton, 2010, Bernhardt, 2016). In the same vein, Lahiri-Dutt (2014) showed how land and water in Western thought were split into disparate categories, with land defined "as the part of the earth's surface that is not covered by water" (Oxford Dictionary, cit. in Lahiri-Dutt, 2014). Today flooding is generally defined as an overflow of water onto "normally" dry land (Arnell, 2002).

The protection of dry land from flooding is often related to the protection of economic activities since "watery land" is generally considered non-productive (Lahiri-Dutt 2014). The British colonial government in Bengal, India, for example, aimed to control the rivers in order to stabilize the land as a source of revenue (D'Souza, 2009, cit. in Lahiri-Dutt, 2014). In another account, Mehta (2007) showed how hegemonic narratives of water scarcity in India legitimized large-scale technical interventions in water flows. Water conceptualization itself is thus an intrinsically social and political activity (Boelens, 2014) and water circulation and control in this way often internalizes and expresses power relations. Indeed, research on the production of irrigation and drainage systems (Barnes, 2014, Swyngedouw, 2015), water supply systems (Kooy & Bakker, 2008, Bakker, 2003) or river flows (Bouleau, 2014), all highlight how political, economic and cultural ideas about water and flooding become physically inscribed into the landscape. Understanding the material and symbolic dimensions of how natural resources come to be imagined, controlled and contested as hazards therefore opens up the socio-cultural as well as political dimensions of risk production for analysis (Jones et al., 2014).

3. Research approach and methods

The research conducted for this paper was part of the interdisciplinary research project (*EFForTS*). The project explored socio-ecological impacts of the expanding plantation business in Indonesia. Jambi province constituted the site of research due to the ongoing rapid land use transformations in the province's lowlands. Interest in the production of flooding as a hazard emerged during initial field visits to Jambi province in 2015 and 2016. These visits aimed at creating a broader understanding of the kind of challenges people in Jambi were facing with regard to the governance of natural resources. It quickly became apparent that flooding was considered a threat to local development across the province. What intrigued us, however, was how this contradicted the fact that flooding had always been a seasonal phenomenon in this part of the wet tropics. To explore this contradiction, the first author conducted empirical qualitative field research. The focus was put on two sub-districts in Jambi's lowlands that differed in their physiographic as well as socio-cultural characteristics. The sub-district Air Hitam (Sarolangun regency) is located in the inner lowlands of Jambi province, while the sub-district Mendahara Ulu (Tanjung Jabung Tibung regency) is located in the coastal peatlands. Both sub-districts overlap with small watersheds, the Air Hitam and the Mendahara rivers. Along each of these two rivers, three to four villages were selected for study. The time spent in each village varied between one and four weeks. In total, the first author lived in Jambi province for ten months, in the period September, 2015 to December, 2017.

Semi-structured interviews, informal interviews, participative observation and group discussions were the main methods applied. 99 semi-structured and 64 informal interviews with villagers were conducted. The interview partners were chosen according to snowball and purposive sampling methods (Flick, 2016). At the village level, these included research participants representing local institutions such as government bodies, farmer groups or civil society groups, and people directly affected by flooding at home or on their plantations. These included interview partners across different social groups, such as people born in the area, spontaneous and state-settled migrants, food crop and plantation farmers, as well as poorer households and village elites. Initially the interviews were translated into English by a local student assistant; later the first author conducted the majority of interviews directly in Indonesian. This language proficiency facilitated numerous insightful informal conversations and helped to build trust and recognition between the researcher, the assistant and the interview partners. This level of intimacy was further enhanced as several households were interviewed repeatedly during consecutive field visits, combining both formal and informal interview situations and involving different members of the households. Repeated field visits and interview situations enabled us to re- and cross-check findings and interpretations with our interview partners as well as to gain insights into local dynamics. Visits to villagers' and companies' plantations, different river sections and protected forest areas further helped to interrogate the meaning of flooding at the affected places. External perspectives on local developments and insights into local and regional policy making were gained through an additional 32 interviews in (sub-)district and provincial capital cities with representatives from academia, civil society organizations, government offices and the private plantation sector.

Formal interviews were recorded and transcribed in Indonesian. All interview notes and field memos were coded for content using MAXQDA software. Finally, empirical research data was complemented by a review of literature on historical land use patterns and the importance of rivers and floods for culture and economy in Jambi province.

4. Results

4.1. Living with rising water – hydrosocial relations in Jambi's lowlands until the mid 1980s

First villages in Jambi's inner lowlands were established by Malay people who explored new territories in Southeast Asia by moving upstream on the large rivers. Until the mid-1980s sedentary agriculture centered on the larger riverbanks and was well adapted to seasonally changing water levels (Scholz, 1988, Locher-Scholten, 2004). The Air Hitam sub-district exemplifies this. During the dry season villagers collectively cultivated dryland agriculture such as corn, rice or soybean on natural river dams. Some alluvial floodplains were cultivated with wet rice. Adjacent to the agricultural fields, rubber agroforests were developed. These turned into the mainstay of the local economy around the mid 1970s but did not extend beyond a stretch of a few kilometers from the riverside. The forests further inland were scarcely inhabited by semi-nomadic indigenous groups practicing slash and burn agriculture (Steinebach, 2008). Peat and swamp areas, located south of the Air Hitam River (Fig. 1), were used only for hunting and fishing and remained forested. The floodplains of the Air Hitam River were protected under customary law as local spawning grounds.

The coastal swamp and peatlands of Jambi province, including our case study site Mendahara Ulu, remained scarcely inhabited until the turn of the 20th century. During the following decades, migrants from South-Sulawesi, South-Kalimantan and partly also from Java settled along the coast and started moving inland (see also Scholz, 1988, Claridge, 1994, Galudra et al., 2013). In our case study area first settlements were established in the 1970s. After the strenuous clearing and draining of the swamp forests, settlers established land use systems based on their agricultural knowledge developed at the coast. Riverbanks were dominated by tidal rice cultivations and the adjacent shallow peat soils were planted with coconuts. As population numbers increased, newly settled migrants gradually started converting deeper peat areas, further away from the Mendahara River, as well as areas further upstream of the river. Cultivation systems generally did not yet extend further than 5–8 km from the riverbanks and the particularly flood-prone areas in the southern peatlands of Mendahara Ulu remained largely uninhabited. In the 1980s, a private company obtained a logging concession of almost 18,000 ha in the peat swamp forests adjacent to the villages. Logging, in the following years, turned into one of the most important sources of income for many farmers and resulted in a gradual abandonment of their rice fields.

The rivers in both regions served as the main mode of transportation and enabled barter trade with and between upstream and downstream villages (Locher-Scholten, 2004). As an older woman born in the Air Hitam sub-district expressed in an interview, the river was considered the "place of living" (*tempat hidup*). It was the place for the market, transportation and housing. It also provided water for drinking, bathing, and washing. Boomgaard (2007) tellingly referred to the Malay people as a "water people". Fishing was a common source of income in both sub-districts and constituted an important social activity. Whenever people recounted about fishing, they often started reminiscing about the abundance of fish and the particularity of local fish species. Villagers living in stilt houses in the peatlands also remembered that during flooding they could fish directly out of their windows and doors and that shrimps would swarm around their feet whenever they went bathing in the rivers. In the peatlands, this condition remained until recently. The head of a village hamlet who had moved to the area in 2001 remembered the ease of fishing:

> In the past there were still many fish, so many. Some of the villagers went fishing […] they could even earn their living with fishing. […] We only sold it [the fish] here in the village. Because the people from Jambi [city] came here to pick up the fish. We only put it in front of our houses. In the past the water was still deep. That's why there were many fish. (Mendahara Ulu, March 24, 2017)

Despite this close connection to the rivers, flooding did present problems. It was a source of waterborne diseases and impeded agricultural land use. But to the villagers, flooding was considered a natural phenomenon and the slowly rising water levels in the rainy season did not pose any immediate threat. Floods were referred to as "rising water" (*air naik*) or "deep water" (*air dalam*) and traditional knowledge helped prevent flood damage:

> In the past, we would read the condition [of the weather]. So if there is flooding, we won't plant the rice. But if it is dry, we will go to the fields. […] And until the rice was ready to harvest there was no flooding. Only after we harvested the fields, the floods came. (Head of a local farmer group, Air Hitam, July 17, 2016)

In fact, older villagers recounted that in the past they preferred the rainy season – also called "flooding season" – over the dry season. The latter posed several challenges to the villagers. Before roads were established, transport by boat was often hampered by low water levels during the dry season and water supply in the peatlands was difficult when riverine water turned brackish due to salt water intrusion:

> In dry season life was hard. It was hard to get out of the village. […] And to bring the products into the village. Because the water level decreased. To transport the rubber produce we had to pull the boat. We walked through the river, pulling the rubber. It took weeks until we arrived. (Older Malay woman born in the Air Hitam sub-district, July 13, 2016)

The local rivers also served as central site for identity building (see also Andaya, 1993, Locher-Scholten, 2003, Andaya, 2016). For example, the founding myth of Jambi city - a story which the researcher came to hear in different versions several times during field research - builds on the narrative of a couple traveling downstream the Batanghari river with two goose. These were supposed to indicate to the couple where they should build a new settlement. Until today, the central market in Jambi's capital city is named after these two goose (*angso duo*). Advertized cultural artefacts from Jambi include the wooden stilt houses (*rumah panggung*) or traditional batik cloth decorated with symbols of goose, rivers, and ships. Indications of upstream (*hulu*) or downstream (*ilir*) were used to describe different economic and political systems but also referred to different peoples, cultures, spirits and gods.

4.2. The transformation of hydrosocial relations in Jambi province

4.2.1. The introduction of the agro-industrial plantation business

Large-scale deforestation and land use change in our case study areas was initiated with the rise of the agro-industrial plantation business under the military regime of President Suharto (1967-1998). His national economic development program focused on supposedly "undeveloped" and scarcely populated areas, which included large peat and swamp areas (Scholz, 1988, Galudra et al., 2013). For this purpose, Suharto initiated a resettlement program (*transmigrasi*), that aimed at resettling people from densely populated Java and Bali to Indonesia's outer islands (see also Fearnside, 1997). Large parts of the forested peatlands and adjacent areas in the sub-district Air Hitam, our first case study area, were chosen for such a transmigration project in the mid-1980s (Fig. 1). As part of this program, each transmigrant household received a two-hectare parcel of land, which was developed into an oil palm plantation in cooperation with private companies in the early 1990s. In addition, the companies were granted large-scale concessions for oil palm plantation development adjacent to the transmigrant villages. Subsequently, peat and swamp areas were cleared and plantations and village hamlets were established in the middle of regularly flooded land. Large-scale drainage and road systems were constructed to make this possible. Once oil palm companies had settled, the land use in neighboring Malay villages also changed (Fig. 1). As people born in the area observed the economic success of the transmigrant oil palm farmers, many hoped to benefit from the business as well and started cultivating oil palms on their own. Food crop cultivations that had already decreased with the economic success of rubber plantations, decreased even further.

Rapid land use change continued in the sub-district Air Hitam during the decentralization phase that followed the fall of Suharto's military regime in 1998 when local and regional actors started competing over authority and access to land (Moeliono & Dermawan, 2006). Irregular land sales represented a widespread challenge and concession granting extended into the remaining unprotected forest areas (Barr et al., 2006). In addition, investment and job opportunities in the plantation sector attracted numerous migrants and land investments, spurring the further establishment of plantations, in particular in the remaining forested floodplains and peatlands adjacent to the Air Hitam River. Around the year 2010 they had been cleared entirely.

In Mendahara Ulu, the second case study area, agro-industrial plantation development started several years later than in Air Hitam. In the 1990s, smallholder farmers who had formerly cultivated coconut plantations, started intercropping these with areca nut palms and later also with oil palms. Yet, large-scale land use change only began at the turn of the 21st century after a 70,000 ha forest production concession had been granted to a transnational pulpwood company on the peatlands in the vicinity of our case study villages (Fig. 1). When the company started clearing land to develop acacia plantations, numerous land conflicts also spurred land clearance and plantation development by smallholders who aimed to demarcate their land claims. At the same time the resurfacing of district road in the southern peatlands of Mendahara Ulu resulted in spontaneous in-migration from all over Indonesia as it strongly improved access to the area. Around the year 2012, almost all forests outside protected areas had been gradually cleared in the sub-district.

In both case study areas, the large-scale encroachment of wetland areas was thus initiated by private companies that were granted concessions for plantation development. Once these had started clearing land and through road establishment improved access to such lands, smallholders tried to develop plantations on their own as well. Many of them, however, did not have the financial or technical capacities to profitably manage plantations on these flood-prone lands. They thus opted to sell such lands to wealthier farmers from neighboring villages, migrants or private investors from urban areas. For such actors, wetlands presented attractive investment opportunities as they were sold at a relatively cheap price. Moreover, this land constituted the last continuous areas for sale in the area and thereby also attracted larger investors.

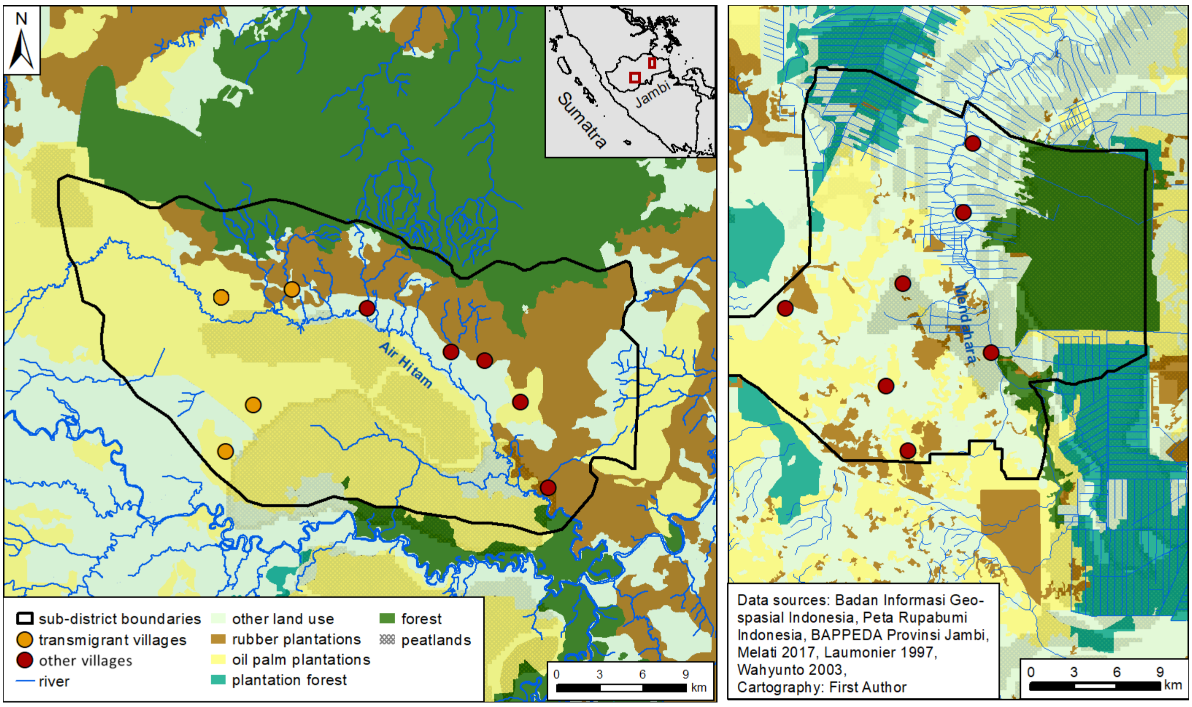

Fig. 1: Land use maps of the sub-districts Air Hitam (left) and Mendahara Ulu (right). The land use displayed is based on a land use classification in Jambi province in 2013 (Melati 2017). The category "other villages" includes different types of non-state planned villages (i.e. Malay villages).

4.2.2. "Flooding is stress. Stress for the oil palm and also for the people" - Changing perspectives on land and water

The introduction of the plantation business in our case study areas not only led to large-scale land use change but also changed many people's attitudes towards land and water. In particular, actors in the plantation business perceive flooding as an obstacle needing to be controlled to enable economic development. A woman from South Sumatra who had bought land in the peatlands of Mendahara Ulu in 2011 explained:

> [When we settled here] there was a lot of empty land. And the price was affordable for people from the middle class. […] When we bought the land, it looked like we were buying a piece of sea. The water had the same height as the road. […] But what was important was that it could become productive in the future. (December 7, 2017)

As a precondition for successful plantation management they needed to get rid of the excess water. The approaches taken varied hugely according to people's individual financial and technical capabilities. Rich investors bought excavators, dug sophisticated systems of drainage channels and heightened the soil under young palm seedlings. Less affluent people also tried to win the battle against the water masses. A local smallholder farmer, interviewed in his plantation in the floodplains of the Air Hitam River, explained that out of 100 oil palm seedlings that he had planted the year before, only 12 had survived the flooding season. Despite this loss, he calculated that if only some seedlings would survive each year, his plantation could provide an income for his children at some point in the future.

For those who could not successfully control the water, flooding resulted in economic and psychic stress. While oil palm plantations are relatively flood resistant, flooding causes young seedlings and fertilizer to be washed away and substantially reduces the palm's productivity. Moreover, these perennial palm trees should be harvested throughout the year, but seasonal flooding disrupts this. A transmigrant farmers, who was designated land in the floodplains of the Air Hitam River, explained the difficulties of managing his plantation there:

> Each time I apply fertilizer, the water comes. Then it [the fertilizer] is lost. […] [The impact of flooding] is stress. Stress for the oil palm and also for the people. […] When the flooding is over, the leaves will turn yellow. The process takes at least three months, only after that the oil palm will be normal again. (June 21, 2016)

With the introduction of the plantation business, in fact, Jambi's entire economy and infrastructure became dependent upon dry land and thus heavily dependent upon flood control. As transport was shifted on to the roads and villages and plantations expanded into wetlands areas, we observed the rise of new businesses selling mineral soil used to build streets and housing foundations on flood-prone land (Fig. 2-3). In particular, transmigrant households adapted to flooding by raising the foundations of their houses. These "modern" houses, however, are much lower than traditional stilt houses and thus continue to be prone to exceptional flooding. In general, the appearance of new actor groups such as (trans)migrants or private investors not used to regular flooding reshaped the local understanding of flooding. As an officer at the provincial watershed agency depicted it, these people were simply not "friends with the water".

Fig. 2 and Fig. 3: Soil pit (left picture) where mineral soil is being sold to build housing foundations in the peatlands (right picture).

4.2.3. "Maybe nature is changing?" The emergence of abnormal floods

The large-scale deforestation and the establishment of plantations, settlements, road infrastructure, drainage and flood control systems have led to gradual changes in water flows. Such changes were first observed following large-scale land clearance but became particularly noticeable since the early 2000s as they began exceeding traditional practices related to flooding. In Mendahara Ulu, flood intensity decreased due to the wide spread establishment of drainage channels. In Air Hitam, on the contrary, flooding intensity was reported to have increased. Big floods, which were said to be common roughly every five years in the past, now occurred almost every year. A young indigenous man explained that while flooding had only occurred near the river in the past, nowadays it would spread over much larger areas. Moreover, he had noted that river water levels would rise much faster than they had risen in the past and, in line with other farmers, claimed that rivers today overflow their banks after only small rainfall events. An older indigenous man and representative of an indigenous rights organization remembered:

> Before the transmigrants came there was less flooding. No matter how strong the rain was, there was no such flooding. There was flooding, but not this strong. [...] Now if it rains just a bit, there is flooding. And only a few days later, it will already be dry again. (June 16, 2016)

In both sub-districts villagers further remarked that flooding no longer followed normal seasonal patterns and had become difficult to predict. Due to the rise of increasingly monocultural plantation landscapes government programs at national and regional scale had recently tried to encourage farmers to cultivate food crops again. But both new as well as old food crop farmers mentioned that it had become increasingly difficult to predict the optimal time to start sowing. An older villager and head of the village farmer's group association explained:

> [In the past] our prediction was still correct, but now it is a bit difficult. We predict dry season, but there is flooding. But if we predict flooding, then it is dry. In the past we were correct, we could predict it. […] But now we are confused, we predict rain, but suddenly it will be dry. Maybe nature is changing…? (Air Hitam, July 17, 2016)

As food crop farmers' fields were often located close to the rivers, sudden floods caused frequent harvest failures. Uncertain flood patterns, together with economic reasons, made several of them convert their food crop cultivations into oil palm plantations, supposedly more flood resistant (Fig. 4). However, the flooding also constrained these.

Fig. 4: Farmer watching his flooded field. This former corn field has recently been planted with young oil palms.

In addition to changes in flood timing and intensity, villagers in both sub-districts complained about a decrease in river water quality. This decrease was attributed to high water turbidity, garbage floating in the water, and a decrease in fish stocks and species. The causes for these changes are multiple and probably a cumulative result of the loss of riparian buffer zones, the frequent use of fish poison, the leaching of agricultural inputs, and the drainage of peat soils. The decrease in water quality presents a serious health challenge, which is particularly problematic in the peatlands. Villagers but also medical professionals considered the large areas of polluted, stagnant water in rainy season a cause of a variety of diseases (Fig. 5):

> Maybe if the water would flow, the garbage would flow away. But here it doesn't, it stays under the houses. [...] The result is that there are many mosquitoes. [...] And then we have outbreaks of dengue and other diseases." (discussion with a village women's group, Mendahara Ulu, April 13, 2017)

The observed degradation of river water changed people's traditional practices of using the river for fishing or personal hygiene. Eating river fish was sometimes even considered a danger to people's health, a claim that was particularly dominant among urban residents. A representative from the provincial government sarcastically depicted:

> In the past when we ate fish it was considered healthy. But now if we eat fish from the bottom of the river, we are afraid that it is polluted with mercury. And fish from the surface of the river is polluted with soap and all types of household waste. So all of them are polluted. (Jambi City, June 12, 2017)

The decrease in water quality has further led to an increasing commodification of formerly public goods, such as fish and water in both our study regions. Governments as well as company funded CSR programs nowadays promote the establishment of fish ponds. Yet, the need for successfully writing funding proposals, makes only well-organized farmer groups benefit from such programs. To prevent the spread of diseases, local authorities and public sanitation campaigns tried hard to convince people to use wells or packaged water for their personal hygiene. However, such campaigns strongly conflict with many people's daily reality and with the role that rivers originally played for cultural identity and social activities. Public campaigns thus contributed to a stigmatization of those still using the rivers and often remained without success. A general practitioner desperately recalled:

> [I tell them] don't use the river! It's so difficult, the mindset of the people here. Since we were children, we always used the river. Even if people have wells, they still use the river. If we use the river, we can swim. But if we use the well, […] I mean, we do not really get wet. (Air Hitam, June 21, 2016)

Fig. 5: Stagnant polluted water in the peatlands of Mendahara Ulu.

4.2.4. "At least the water will flow faster" – Contested attempts to control unruly flood waters

The joint effect of changing flood patterns and the ever increasing expansion of oil palm plantations into wetland areas led to a continuously increasing professionalization of water management among all types of land owners. Smallholder farmers began renting machines from wealthier villagers or regional authorities to dig drainage channels on their plantations. Oil palm companies and private investors equally professionalized their water management systems (Fig. 6):

> Now what we are concerned about is flooding […] When I came back to this area in 2013, I realized that there is flooding because the trees in the national park are already less. So upstream of the plasma [transmigrant] farmers' land we try to divide the water flow into two. We made channels like in Jakarta, one flood channel in the west, and one in the east […] So our hope is, while we cannot prevent the flooding, at least the water will flow faster to the mouth of the river. (oil palm company representative, Air Hitam, June 18, 2016)

Yet, controlling the fluid water remained difficult. In particular in the peatlands, the amount of drained water often by far exceeded the river capacity to carry water flow. Many villagers thus requested governments and companies to "normalize" their rivers, including dredging and widening them to improve water flow. In Mendahara Ulu, where this had been done twice, the effect, however, was not sufficient and villagers requested further initiatives. Respondents further observed that even small differences in the type of the drainage systems could influence whether plantations were inundated or not. A transmigrant farmer owning a plantation adjacent to company land explained:

> The companies cleaned the channels, they use a machine […] But the companies are not the same. For example if there are two companies: in one area they clean the channel, but the company downstream has not yet cleaned it. Or even if the difference [in cleaning] between both is only small: […] if here the water flows fast, then downstream it will clog again. And then the water will rise again. (Air Hitam, June 21, 2016)

Fig. 6: Recently built flood control dam in the Air Hitam sub-district.

Through the construction of large-scale flood control and drainage infrastructures water flows became increasingly embedded in power relations. As they contributed to a spatial and temporal redistribution of flooding, they often aggravated flood damage for the most vulnerable. A smallholder farmer residing downstream of a major drainage channel explained:

> The biggest challenge for the farmers here is flooding. Because PT WKS (the acacia plantation company) has a lot of channels and trenches. If it is very dry, they keep the water in the plantation, but if there is too much rain, they open the channels and all the water flows to the village. […] That is why it is impossible to grow staple crops and vegetables in the village. […] Because suddenly there will be flooding and all the crops die. (Mendahara Ulu, March 25, 2017)

Flooding thus started being discussed as an expression of injustice. It also turned into a source of conflict. Standing on a recently built dam a young Javanese migrant complained that in the past, the company and himself were affected by flooding. After the company had built the dam, however, the company was able to harvest in rainy season, while flooding on his plantation had become even worse. In another case, a newly built dam prevented a smallholder farmer from accessing his land. Enclosed by the Air Hitam River and the companies dam, he destroyed parts of the dam to make his motorbike pass. Villagers tried to oppose the building of corporate dams and drainage channels by filing official complaints. In one case, they even organized a road blockade to impede the company's transport of fresh oil palm fruits. Yet, until the time of research, such initiatives remained without success.

5. Discussion – Turning "rising water" into "flood"

Recent research in political ecology and anthropology offers useful insights into the dialectic relationship between meaning, practices, and materiality in the constitution of water flows. Building upon this literature, our study offers four important insights into how engaging more deeply with hazards and the processes of their production can further our understanding of the production and meaning of risk.

First, examining the production of flooding in Jambi reveals that hazards are not just 'out there', but are, as in the case of risk and vulnerability, the products of socionatural relations. Contrary to dominant framings in public discourse, risk policies and also much risk research, our case study illustrates that flooding does not necessarily constitute a hazard. Definitions of water, and thus also flooding, are rather emergent products of the local economic, socio-cultural and historical context (Hamlin, 2000, Baviskar, 2003, Linton, 2010, Boelens, 2014, Wilson, 2014). Our historically situated analysis of hydrosocial relations in Jambi exemplifies this. Before the introduction of the agro-industrial plantation business to Jambi province, flooding was considered a normal seasonal phenomenon of gradually and predictably rising water levels. Through economic and cultural practices such as fishing or floodplain cultivation, people had built their material culture around this temporal dynamic considered intrinsic to social life (Harris, 1988, Jones, 2011). As in other parts of Southeast Asia, the large tropical rivers had constituted a source of social interaction and livelihood (Boomgard, 2007, Ley, 2018). Moreover, local notions of "deep" or "rising" water reflected that Jambi's people did not draw strict boundaries between land and water. It was less the spatial boundaries between land and water that shaped people's life, but rather what Krause (2017) describes as "the rhythms of wetting and drying". Conceptions of flooding in Jambi were hence shaped less by ideas of "where water belongs" (Walker et al., 2011) and more by expectations of when and how water would rise. Flooding, in consequence, was simply a dynamic gradient of rising water depth and, as also described by others (e.g. Harris, 1988, Baviskar, 2003, Jones, 2011), a source of social life and cultural identity.

However, such definitions of flooding are open and contested and may change over time if social, political and economic or ecological relations are reconfigured (Hamlin, 2000, Linton, 2010, Walker et al., 2011, Jones et al., 2014, Linton & Budds, 2014). In Jambi, flooding as a hazard has been produced by recent political economic change. This change, facilitated by the emerging plantation sector, introduced new frames and imaginations of flooding. Plantation owners, for example, saw water on land as something "out of place" that impeded a profitable plantation management. Similar to what other studies have argued happened during industrialization in the Global North (Linton, 2010, Bernhard, 2016), or during colonization across Southeast Asia (D'Souza, 2006, Lahiri-Dutt, 2014, Ley, 2018), wetlands were framed as useless unless they were drained and flooding as a hazard that threatens economic development. As the plantation business prioritized dry land for economic development, efforts to control water through infrastructural developments have thus resulted in a sharper definition and allocation of where water belongs. These developments further consolidated, in turn, an understanding of flooding and the relationship between land and water that is inherently different to the understanding that had historically developed within the local area. The emergence of the plantation business in Jambi thus started reframing nature itself and also initiated new discourses of risk.

However, what constitutes flooding as a hazard it is also a product of water's specific material traits that put people and objects at risk. In Jambi, infrastructural developments and changes in local ecohydrological processes have altered the materiality of water flows, causing rivers to overflow their banks more often and, according to the farmers, in less predictable patterns (Merten et al., 2020). These changes contributed to changing the local understanding of flooding, too. For water to qualify as a flood, according to Walker et al. (2011) it needs to be provided with an "abnormal quality". In Jambi, actors that have only recently bought land in the area, perceive the mere presence of water on land as something inherently "abnormal". Yet, for people local to the area, only the recent material changes qualify rising water as a hazardous flood. In line with other studies on flooding and land use change, the predictability of flooding is of greatest concern (van Noordwijk et al., 2017, Langill & Abizaid, 2019). It made food crop farmers reconsider their crop choices but also troubled harvesting and fertilizer application of those people managing plantations. Yet others, considered the decreased quality of flood waters as particularly hazardous as it constrains their daily use of the river. Finally, the fluid nature of water adds to its perception as a hazard. As water flows move across the landscape from one plantation to another, strategies of coping with flooding appear insufficient. Gradually, an ever increasing need of managing flooding arose, causing water flows to appear even more abnormal.

Second, reconstructing the changing nature of flooding in Jambi enables us to look beyond the material-economic dimensions of risk. It reveals insights into the social life of natural resources and thus also into the socio-cultural meaning of newly produced material risks, something that is urgently needed in political ecology (Baviskar, 2003, Boelens, 2014, Acharya, 2015). In Jambi, the changing hydrosocial relations have marginalized the role that flooding historically performed for social life in Jambi. The so-called "water people", are increasingly kept away from drinking, bathing or fishing in the rivers, which are now deemed polluted and dangerous. The river, or the historical "place of living", has also lost its former functions such as transportation and providing a location for markets and joint communal activities such as crop rotation or fishing. These changing hydrosocial relations thus gradually contributed to a loss of material practices related to flooding and, subsequently, a loss of its importance for cultural identity. On the contrary, they even contributed to a stigmatization of such practices. Discourses labelling traditional practices of using the river as unhealthy and culturally backward have been prevalent in many parts of Indonesia since colonial times. They helped colonists and subsequent governments to establish their moral superiority and also contributed to the development of socially segregated urban water supply systems (Kooy & Bakker, 2008, Engel & Susilo, 2014, Ley, 2018). In rural Jambi, such discourses have clearly been strengthened through a visibly deteriorating water quality. Finally, while flooding in the past was a source of communal activities, today it is a source of conflict. In fact, many smallholder farmers had embraced the fact that cultivation practices were constrained through seasonal flooding. It only changed after technical interventions in water flows made flood damage spread unevenly between spaces and people. Rising water flows today are also considered "abnormal" as they have become expressions of social injustice, reflecting the growing social inequalities across rural communities in Indonesia (McCarthy, 2010, McCarthy, 2012, Beckert, 2016, Obidzinski et al., 2016, Merten et al., 2016).

Third, reconstructing the historical production of flooding as a hazard can facilitate the study of the interactions between social and biophysical processes and reveal contradictions in the socio-ecological configurations that are constitutive to the production of risk (Harvey, 1996, Oliver-Smith, 2002). Due to the dialectic relationship between meaning, practice and materiality such shifting ontologies of environmental processes lead to different ways of dealing with the environment (Jones et al., 2014, Oliver-Smith, 2002, Linton & Budds, 2014). Framing flooding as an obstacle for economic development and a threat to people's health, in Jambi has legitimized technical interventions to control its flows and public recommendations to refrain from using river water. But this separation material and discursive separation of water from its context strongly contradicts the biophysical environment. It creates what Whitt (2018) calls a "cyclic dissonance" between cycles of water and people's uses of land, producing new spatial patterns and temporalities of flood risk. Moreover, it contributes to the emergence of path dependencies towards ever more financially and technically demanding needs of managing the "uncooperative" (Bakker, 2003) water flows. These technical interventions reflect existing power relations and thereby exacerbate unequal landscapes of risk and vulnerability. In many Indonesian coastal cities, such techno-managerial risk approaches contributed to implementing specific ideas of development in urban space. As "illegal" residents along the rivers and their "unmodern" practices of using the river, for example, were blamed for flooding and other river-related problems, their eviction was often justified through flood protection policies (Kooy & Bakker, 2008, Van Voorst & Hellmann, 2015, Octavianti & Charles, 2018, Ley, 2018, Dovey et al., 2019). Engaging with the production of the hazard thus allows us to map out the produced nature of environmental risks, unmasking the social processes behind physical events, something ever more important in the Anthropocene and in this era of global climate change (Mehta, 2007, Ribot, 2014, Oliver-Smith et al., 2017).

Ultimately, and hence fourth, tracing such changes in a society's understanding of environmental processes may also provide valuable explanations for future developments. A variety of risk studies have shown, how risk representations may become hegemonic, as they manifest in policies or risk assessments, thus naturalizing scarcity or risk (e.g. Mehta, 2007, Fernandez, 2014). While we did not explicitly analyze how the changing frames of flooding are taken up in water policies in Jambi, we have come across several recently developed watershed management plans and flood risk assessments during our field research. Understanding changes in the ontologies of environmental processes may thus provide useful explanations for how such new risk policies are produced and legitimized. As shown by Ley (2018), representations of coastal marshlands as dark, uninhabitable and criminal spaces have established river "normalization" (dredging and embanking rivers) as a cure for flood risk management in the Northern city of Semarang, Indonesia. It has further worked to spread norms of urban conduct and "right" development. While technical interventions in water flows in rural Jambi are seemingly not (yet) associated with normative development programs, calls for "normalization" as a solution to flooding have become widespread.

6. Conclusion

In this article, we showed how the meaning of flooding in Jambi province has changed from seasonally rising water to hazardous flooding. We did so by approaching flooding as a socionatural production and investigating past and present symbolic as well as material dimensions of flooding. We showed how the expansion of the agro-industrial plantation business altered physical water flows and changed people's ways of engaging with floods, materially as well as discursively. In our study, it becomes clear that today's economic relations strongly contradict Jambi's wet physiography, thereby leading towards a path dependency on water redistribution that reflects and reinforces uneven power relations under Jambi's new political economy and marginalizes the traditional role of flooding in social life.

In conclusion, we argue that engaging more thoroughly with the socionatural production of the hazardous event itself may benefit much risk research. Engaging with relational perspectives on water and natural resources, developed in political ecology and anthropology, provide important lessons for that. They enable us to focus not only on biophysical changes but also the cultural and symbolic dimension regarding when water turns into a flood and how this is shaped through local history, geography and culture. Moreover, engaging with relational perspectives on water and natural resources serves to reflect on contradictions and tensions present in current socio-ecological configuration, thereby allowing us to explain the increasingly systemic nature of environmental risks.

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Author contributions

Jennifer Merten: Conceptualization, Methodology, Investigation, Validation, Formal analysis, Project administration, Funding acquisition, Visualization, Writing - original draft, Writing - review & editing. **Jonas Østergaard Nielsen**: Supervision, Writing - Review & Editing. **Rosyani:** Project administration, Writing - Review & Editing. **Endriatmo Soetarto:** Project administration, Writing - Review & Editing. **Heiko Faust:** Supervision, Conceptualization, Project administration, Funding acquisition, Writing - Review & Editing.

CHAPTER V:

Indonesia's Fire Crisis 2015: A Twofold Perturbation on the Ground

Flora Hartmann, Jennifer Merten, Michael Fink & Heiko Faust

Abstract

Wildfires in tropical rainforests and especially peat fires have abundant and wide-ranging negative effects on the economy, ecology and human health. Indonesia has large areas of peat swamp forests that recurrently burn. The use of fire is the most common method for land clearing in Indonesia. As a reaction to the devastating fire events of 2015, the provincial government of Jambi reimposed a more stringent version of the prohibition of burning land, delegalizing this land clearing method for smallholders. From a local perspective through qualitative research at the village level it becomes clear that this regulation is maladaptive as the underlying cause making land prone to fires, the sinking ground water table, remains unchanged by the ban. Further, the impacts of the new regulation vary for different groups of the local population, with severe land management restrictions for food crop farmers. The application of a framework on the political and material dimension of vulnerability reveals that the national policy unintentionally causes economic hardship and landscape changes at the local level. Hence, smallholders have experienced a two-fold perturbation caused by the fires' impacts and the reinforced ban on burning land.

Keywords: Indonesia, peat fires, vulnerability, maladaptation, governance

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1. Introduction

Frequently, uncontrolled large-scale peat and forest fires in the tropics pose a threat to the affected regions' integrity regarding ecology, economy and human health (Alencar et al. 2006, Cochrane 2009, Gross 2015). As the resulting toxic haze contains an enormous amount of fine particulate matter (Koplitz et al. 2016) and does not stop at national borders, tensions between nations are likely. With the 1997 fire events which "blanketed" (Frankenberg et al. 2005: 109) large areas in South East Asia, the issue attracted attention from public, scientific and political actors for the first time (Carmenta et al. 2017, Davies & Unam 1999, Fanin & van der Werf 2017, Lin et al. 2017). Supranational institutions such as the Association of South East Asian Nations (ASEAN) reacted to the risks of fire and associated pollution and haze and have urged their member states to prevent fire events as with the 2002 Agreement on Transboundary Haze Pollution (Lin et. al. 2017). Nevertheless, large scale peat and forest fire events still occur, especially in Indonesia. Most recently, the fire events of 2015 caused the burning of 2.6 million ha of Indonesian land (World Bank 2016). Each day, the emissions caused by the fires in 2015 surpassed the daily emissions from the whole USA (Carmenta et al. 2017). Ecosystems suffered (Lee et al. 2017) and the economic loss is estimated at USD 16.1 billion to Indonesia alone (World Bank 2016). The 2015 fire event coincided, like the one in 1997, with a strong El Niño Southern Oscillation, ENSO (also referred to as El Niño), that causes a prolongation of the dry season and a reduction in annual rainfall (Fanin & van der Werf 2017, Koplitz et al. 2016). Monsoonal winds carried the pollution haze to Malaysia and Singapore. Consequently, around 69 million people were exposed to an extremely high particulate pollution (Crippa et al. 2016) which led to the premature death of approximately 100,300 people (Koplitz et al. 2016). National and international pressure forced the Indonesian government to adopt adequate measures to prevent the burning of land. In Jambi province, one of the hotspots of the fires, a new regulation was issued that banned the burning of any land and imposed a penalty of up to ten years imprisonment.

Against this backdrop we claim that the prohibition on burning land is an insufficient attempt in the long-term prevention of large-scale fires in Indonesia. This article builds on an in-depth qualitative case study. Its conceptual approach follows the basic idea of political vulnerability, which describes the translation of materialised harm into measurements undertaken by politicians. The ban on fire as an agricultural tool demonstrates how susceptibility to harm caused by change in the biophysical sphere is linked to political change. This change, in turn, is an example for a mismatch between its intention to reduce the local population's, and biophysical spheres' susceptibility to harm, and its outcome as it does not address root causes thus fostering unintended land use change. As a starting point, we analyse the effects the exceptional 2015 fire events had on income and health, referred to as material vulnerability, followed by the impact of the fire ban, and people's adaptation to it.

Fig. 1: Haze during the day, September 2015. Source: Local villager

2. Maladaptation through Disconnected Scales in Policy Making

Our study of the fire events in 2015 builds on elements of vulnerability assessment literature. Within vulnerability research the focus is on socio-environmental relations, which we enrich with the concept of material and political dimensions of vulnerability (Simon & Dooling 2013). From this perspective human-environmental interactions are the core of the creation and manifestation of vulnerabilities. A widely adopted definition of vulnerability was developed by Adger (2006) who considers vulnerability as “the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt” (ibid. 268). Such an environmental or social change that forms a spike in pressure exceeding ordinary variability has often been referred to as perturbation (Gunderson 2000; Tomimatsu et al. 2013, Turner et al., 2003). An example of a perturbation is a longer than usual dry period.

Taking a context-oriented approach to vulnerability, we consider vulnerability as a recursive process that is dynamically formed through the combination and interaction of social, ecological, economic, and political structures and conditions (Adger 2006, O’Brien et al. 2007, Räsänen et al. 2016, Ribot 2014, Turner et al. 2003). Simon & Dooling (2013) have taken another important analytical step in vulnerability research by stating that it is not sufficient to discuss vulnerability in the singular but rather to distinguish between material and political vulnerability. The material vulnerability refers to material conditions that may be lived and experienced by local communities. The political vulnerability then represents its translation and interpretation by complex governance arrangements. This political responsecan take any form and can be e.g. a measurement, or even no action at all. Disconnections between the material and the political vulnerability may reduce the efficacy of formal policy and community responses and even lie at the heart of maladaptive outcomes. We understand maladaptation as outcomes of intentional adaptation policy that exacerbate peoples’ conditions of material vulnerability (Juhola et al. 2016). Oftentimes, these are the result of non-representative and inequitable governance structures (Lynch 2012) across different scales. We regard this distinction as a means for pointing out the disconnection between the material and political vulnerability as it enables the identification of the underlying causes for vulnerability. In this paper, scales are not regarded as fixed levels or natural entities but as socially constructed (Anssi 2004, Hein et al. 2015). In our case study we consider the individual, household, provincial, national and global level as relevant. Perturbations and the impacts of adaptation measurements may arise from one scale and may manifest themselves in another one.

3. Introduction to the Study Site and Applied Methods

Field research was conducted in the village Seponjen in Jambi province, situated in the south-central part of the island of Sumatra, Indonesia. An overview of the village's location is displayed in Figure 1. Jambi Province was chosen as a research region due to its comparatively rapid agricultural transformation processes. For the past 30 years, vast forest areas of agroforestry systems have been converted into oil palm plantations (Clough et al. 2015). In 2016, oil palm plantations extended over 474,000 ha (BPS Provinsi Jambi 2017), and rubber plantations over 664,000 ha (BPS 2017). Staple crop cultivations (rice, corn, soybean) in 2015 were only grown on 136,000 ha (BPS 2015)

and are increasingly being replaced by more profitable plantation land use systems. The coastal areas in Jambi province are characterized by vast peat areas (Miettinen et al. 2016). The transformation of peat swamp forests into land suitable for agricultural purposes accords with the trend in Sumatra, Borneo and Papua Island. Formerly regarded as marginal agricultural land, peat land has experienced an increase in exploitation for plantation systems which is accompanied by drainage and degradation (Carmenta et al. 2017). The scarcity of land in Jambi Province has driven state promoted resettlements (Kunz et al. 2016), large-scale issuing of concession areas (Kunz et al. 2017) and spontaneous migration of independent smallholders seeking a better future in the plantation sector (Hein 2016; Kunz 2017). During the fire events burning from June until October 2015, 123.000 ha of land burned in Jambi province (World Bank, 2016), which lead to persistently hazardous levels of smoke (Koplitz et al., 2016), causing an economic damage of 866 million USD. Hereof, 210 million USD account to losses in agriculture (ibid.). An impression of the fire events in Jambi can be gained from Figure 2, 3 and 4.

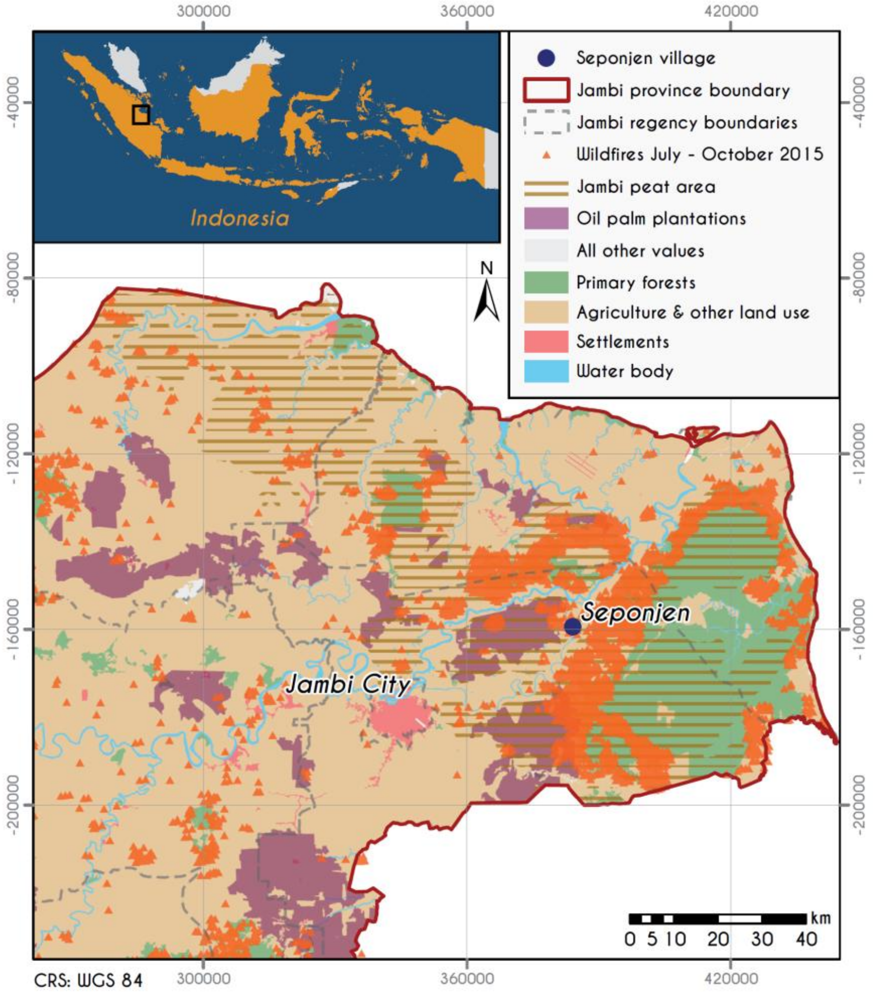

Fig. 6: Localisation of the research village and forest fires 2015 in Jambi province. Cartography: F. Hartmann & P. Hermes, Institute of Geography, University of Göttingen, 11.01.2018. Sources: GDMA - Global Administrative Areas, OSM -OpenStreetMap, Global Forest Watch.

As can be seen from Figure 1, most of the fires occurred in Jambi's vast peat lands. Peat is an organic soil. It consists of partly decomposed plant remains holding less than 20-35% mineral content (Turetsky et al. 2015). The key regulator of peat accumulation and peatland decomposition is water-table depth. If the depth of the water-table is lowered, aerobic conditions stimulate decomposition; thus, peat carbon is released to the atmosphere (ibid.). Deforestation and drainage generate "favourable conditions for the fires and amplify the hydrological drying processes in the aboveground fuels and the underlying organic soil" as they influence the groundwater table (ibid. 1). Due to a high moisture content, the peat swamp forest in its pristine state is "naturally protected from burning" (ibid. 11), whereas large scale degradation by drainage makes peat flammable (Couwenberg et al. 2010) and transforms peat from a carbon sink into a carbon source (Carmenta et al. 2017). Considering the thickness and thus the volume of peat measured, Indonesia holds 46 Gt and 65% of all tropical peat mass (Page et al. 2011).

One distinctive reason why fires were so intensively combustible in 2015, distinguishing it from all preceding El Niño years with prolonged droughts, is the advanced degradation of peatlands and the ongoing change in land-use. Taufik et al. (2017) link the hydrological drought to the fire-proneness of the humid tropics in Jambi.

The village Seponjen was selected for our case study due to its proximity to several hotspots of the 2015 fire events. The dominant soil type in the village are peat soils with a depth of up to four metres, however there are scattered fields on mineral soil or thin peat layers that are already degraded. The village is populated by different ethnic groups, the native Malay people, immigrated Bugis from Southern Sulawesi and other migrant groups from Java. The main income for local households is derived from agriculture. While most farmers focus on oil palm business, some also cultivate maize which became popular in the village with the arrival of the Bugis people in the late 90s and is still dominantly grown by them. Illegal logging of nearby peat swamp forest was a major source of income until the early 2000s. An industrial oil palm plantation concession borders the village; here villagers offer their labour power (interviews with villagers during February and March 2017).

During a two-month field stay in Jambi province we conducted thirty semi-structured and unstructured interviews in February and March 2017 with villagers in Seponjen. Interviews were conducted in Bahasa Indonesia and translated with the help of a field assistant. To acknowledge the heterogeneity of the village population we interviewed a variety of villagers, from village leader to the head of customs to common farmers of different ethnicities and landless families. The main topic discussed during the interviews was the prevailing impacts of the firesto local livelihoods and people's adaptation strategies to prevent future fire outbreaks. During the field visit it became apparent that apart from immediate impacts of the fires, the new provincial regulation on the prevention of forest and land fires had major impacts on local land management strategies. Hence, these dynamics became a second and unforeseen topic of research. All interviews were recorded, partly transcribed and documented in detail. Interview data was further supported by participative observation, photographs taken by our respondents, as well as a review of government regulations.

4. Results: Ground Perspectives on Perturbations

4.1. The first Perturbation: Immediate Impacts of the Fire

As the agricultural sector is the main income for villagers of Seponjen, economic losses caused by the fires largely manifested there. This situation was intensified by low crop yield of the forgone months brought about by the outstandingly long drought. Without exception, all oil palm smallholders reported their fruits had become trek, an expression that describes the phenomenon when fruits of the fresh fruit bunches become lighter and smaller. However, the impacts on plantation productivity differed depending on farmers' management practices as well as whether plantations were only impacted by drought and pollution haze or also suffered tree loss due to fire. A lower production was reported to have had lasted up to three months after the fire incidents. Such losses in income put smallholders under financial pressure. These circumstances were intensified by extra expenses mitigating adverse effects of the drought and fires. Additional costs included spending on medical treatments and clean water for washing, bathing and drinking. Natural water resources, usually serving these purposes, were polluted by dust and particles, and wells ran dry. The severity with which the income losses affected the households varied widely from simply a shortfall in savings to a need for actions such as gaining additional income from other sources and cutting expenses. The most popular method to compensate for the income losses was to gain income as a day labourer on either another farmers' or companies oil palm plantations. Along with the endeavour to counterbalance the losses, cutting on expenses stands to reason. Most popular was cutting down on food costs by a change in nutrition habits, a reduction in quantity of food and a forego of non-vegetarian sustenance. Further, a common strategy among parents was to consume less, thereby leaving enough food for their children. Chemical fertilisers generally required for the management of oil palm plantations were often intermitted during the 2015 fire events due to their high cost, causing further decreases in productivity of the palm trees in the following months.

Health issues proceeded from people's exposure to the pollution haze and smouldering peat which contained high concentrations of Particulate Matter (PM) with diameters of less than 10 and 2.5 μm, also referred to as PM10 and PM2.5 (Koplitz et. al 2016). From the beginning of September 2015 until the end of December the same year, air quality in Jambi's peatlands regularly reached very unhealthy or even hazardous levels according to measurements of the Pollutant Standard Index (PSI) (see Crippa et al. 2016 for more details). Every respondent experienced breathing problems; all experienced sore eyes, some suffered from psychological trauma. Additionally, a decline in water quality lead to several cases of diarrhoea. Exposure of and sensitivity to the pollution haze and smouldering peat and access to coping were largely determined by three factors: (1) age (2) time spent exposed to the pollution haze and (3) economic background. Young and elderly people, as well as those with pre-existing lung or heart diseases, are a high-risk group as they are particularly susceptible to harm (WHO 2013). The duration people spent exposed to pollution haze varied, so did awareness and knowledge of associated health risks. Further, profession and economic background mattered as different occupations involve outdoor activities, such as being a farmer. As most people of Seponjen are farmers they were under economic necessity to work on their fields and plantations or to guard them, thus enduring exposure to pollution haze. Given the fact that economic resources determine the amount of money available for quality construction materials, people with less financial capital tend to live in houses made of wood compared to wealthier people living in houses made of concrete. These types of houses differ strongly in their efficiency to exclude outdoor air as the houses made of wood have a high number of interstices between the wooden boards forming the walls and the floor. Less tangible is the phenomenon of psychic trauma, which were relived in cases where people had experienced losses caused by burnings of their fields and plantations in previous times. Hence, the individual's exposure and sensitivity towards perturbations varied.

Fig. 3: Reduced visibility due to the haze, August 2015. Source: Jennifer Merten

4.2. The Second Perturbation: The Prohibition on the Use of Fire

As a reaction to the fires, the provincial government of Jambi issued a regional regulation which specifies penalties for burning land and forests (Peraturan Daerah 2-2016). The regulation defines the exact modes of the implementation of the national laws No 41/1999, No. 32/2009 and No 30/2014, and goes further as it prohibits burning any size of land, although national law actually states that a person is allowed to burn land of up to 2ha (UU 32/2009). The ban on fire as an agricultural tool to clear or prepare land was introduced in Jambi in March 2016, shortly after the fires had stopped. This ban is a major interference with the farmers' custom, as burning is an integral element of their land-clearing practice. A major problem for the smallholder that comes along with the ban is the disposal of organic material, for which they know of no alternative to burning. That problem concerned seasonal crop farmers immediately since it was their method of preparing their fields every year prior to a new growing cycle. The government proposed collecting organic material manually and then burning it in a barrel as an alternative to clearing the land with fire. The disadvantages to this proposed method are (1) it is very time consuming, (2) is lacks accuracy, and (3) the loss of the fertilizing function. According to villagers interviewed, before the ban on fire one person could manage to clear 2-3 ha of field on his or her own, but without the use of fire in the same time one could only manage 0.5 ha. By reason of the lessened accuracy of land clearing an increase in pesticides was predicted by the smallholders. Commonly used pesticides are glyphosate and paraquat, with paraquat being banned throughout the whole European Union (ECCHR, n.d.). Further, the temporarily fertilising function of clearing land by burning is lost, too. One respondent freely shared his documentation of the maize growth which can be seen in Figure 5 and 6, his proof of the fertilizing function of burning above-ground biomass. The maize seedlings in both figures were planted on the same day, but only one field had been cleared with fire. While farmers highlight the fertilizing and pH-buffering function of burning organic matter on organic and peat soil, this practice contradicts scientific evidence. The fertilizing effect of burning the above-ground biomass which impels a rapid release of nutrients into the soil is only temporarily (Glaser et al. 2002). The burning of peat soil is also problematic as it creates unfavourable conditions for cultivation on the already nutrientpoor soil in the long term and causes peat oxidation (Dikici & Yilmaz 2006; Hirano et al. 2014).

In the villagers' opinion, the law is a heavy burden for smallholders and highly impracticable. Out of fear, the majority of the respondents stated they will, nevertheless, obey. Well known is the case when a farmer of a neighbouring village used fire to clear his land, whereupon he was sought by the police but ran off. His land became state property. In spite of this story, some villagers admitted planning to burn secretly due to a lack of alternatives. In general, opinions on the law among the villagers interviewed were deeply divided.

In 2014, Seponjen was the largest maize production site in the district Muaro Jambi (interviews with villagers during February and March 2017). Where the land for maize cultivation, carried out primarily by Bugis farmers, must be absolutely clear and follow a strict schedule as it can only be planted once a year in Seponjen, oil palm smallholders are more flexible in their proceeding and the oil palm's requirements concerning the clearness of the land are lower. An advantage of burning land is the rapidity and thoroughness which cannot be achieved via manual weeding. The timeslot when maize seedlings have to be planted is very short. Usually, cultivation starts in May when the annual flooding is over. If weeds are cut manually and planting is then postponed, the harvest may fail as monsoon starts and the fields are frequently inundated. Hence, it is not just the accuracy in land clearing that is a major problem for maize cultivation but the timing which is gravely hampered by the ban on fire. As explained by some farmers, this is a reason why the ban might have an influence on crop choice and even trigger land-use change from maize to oil palm. Another concern about a side effect of the law were raised by some interviewees. Attempts in cultivating maize despite the given circumstances or the transformation of maize fields to fallow land might lead to an increase in available organic fuel which plays an essential role in the uncontrolled spread of fires.

After the reinforcement of the ban in 2016, around 20 people cultivated 60 ha of maize. Prior to the ban, about 80 people cultivated 200 ha maize. These numbers only refer to maize farmers organised in farmer groups who may apply for free seedlings from the local government. At the time of our research in March 2017 one farmer group of Seponjen had already withdrawn their proposal for maize seedlings, as it was likewise considered by another farmer group. Individuals had already resigned from maize farmer groups. Other farmers wanted to wait and see whether the prohibition of burning land would be altered again in the coming season and, if the prohibition was unchanged, stop cultivating maize. It is expected that the land formerly used for maize cultivation is either transformed to fallow land or changed to another crop like the oil palm. A change to another seasonal crop like watermelon or pineapple with less organic waste production is not an option as knowledge on how to cultivate other crops and profitable land use options is not a given. Other crops are rarely cultivated as there is a long history of private and state-owned oil palm companies in Jambi where farmers often received training. Also, farmers would incur high investment costs for other seedlings as maize seedlings are governmentally funded for members of farmer groups, although these costs vary depending on seedling and fertilizer quality chosen.

Similarly to the impact of the first perturbation, villagers are affected differently. The degree to which the law disadvantages smallholders is explained in the village's specific cropping pattern. Especially affected are maize farmers, more precisely the ethnicity of the Bugis as they are the main maize cultivators in Seponjen. Hence, the law causes unintended dynamics leaving foremost maize farmers, and thus most Bugis the worst off.

5. Discussion

So far, analysis of the ecological, economic and health impacts of the fires 2015 remained on a national or regional scale (World Bank 2016, Lee et al. 2017, Crippa et al. 2016), leaving a blind spot on how the impacts manifested themselves on the ground. The drying of peat soil has been associated with the creation of conditions that favour the spread of fires (Turetsky et al. 2015, Couwenberg et al. 2010), but has not yet been considered with regard to fire policy. Only with the knowledge of both an understanding of the changes the law brings about in the village and an awareness of characteristics of peat soil can the significance of the ban become clear and demonstrates how it fails to address the underlying causes for the outbreak of fires. To reiterate, a combination of influences out- and inside the village area, namely the expansion of oil palm monocultures on peat land caused the degradation of peat swamp through drainage, fostered by, among others, the Indonesian national government due to land scarcity and a growing global demand in palm oil. Private plantations in Seponjen and an oil palm concession bordering the village on peat soil are an outcome of these influences. These conditions created on the local scale an environment that favoured the outbreak of fires, as dry peat is easy flammable. The dryness of the peat is intensified by the phenomenon El Niño which manifested itself as a prolonged drought. These changed environmental conditions are the Material Vulnerability in Figure 7. How the twofold perturbation of the fire crises in 2015 is fostered by and connected to influences out- and inside the village is depicted in Figure 7. This figure is a timeline connecting a simplification of the events on the household/individual scale to the local and provincial/national and global scale. The arrows connect the different events, the arrow's line informs about the quality of the scales' connectedness. Whereas an unbroken line illustrates a high level of connectedness, a broken line indicates inconsistencies. If an ideal connectedness is a given, the political translation of the material vulnerability meets the aim to reduce vulnerabilities, hence the material vulnerability is mitigated.

In consideration to the given evidence, it is apparent that the major cause making land prone to fires – the sinking ground water table through drainage – is not corrected by the regulation on not burning organic matter on land. Thus, the fires arethe driver of the first perturbation the local population went through. This first perturbation is the direct cause for the Material Vulnerability at the household and individual scale which manifested themselves as the explained adverse effects.

The reaction on the regional scale the ban on the use of fires as a political translation of the material vulnerability is highly disconnected from the local reality. The ban does not tackle the changes that made the land so prone to fires – the sinking ground water table in peat lands through drainage. It is clear that without any kind of compensation or further assistance the ban is highly impractical, hence it is titled as a second perturbation to the villagers as it brings about adverse impacts on their income and makes them more susceptible to economic shocks. A further consequence of the ban is its potential to drive the change from seasonal crops to oil palm. However, this change does not provide a solution to all the villagers' problems as it is not financially viable for everyone and the pressing issue of the disposal of organic matter is not eliminated but adjourned. Maize farmers in particular are hindered by the regulation as their organic disposal comes in high quantities. If the ban on fire is to be successful, the needs of the people on the local scale must be addressed as there is currently no known alternative in land clearing methods. The potential magnitude of future fires is also affected by the varying acceptance of the ban among the villagers. While some plan to obey, others state they will ignore the law as they recognise no danger in burning their land beyond the disadvantages associated with the regulation. Exactly here lies a danger. If the ban is obeyed only by a few people, more dried organic matter remains on the fields or fallow land which is, in case of an uncontrolled fire, easily flammable fuel.

Hence, vulnerability has increased in terms of (1) susceptibility to economic shocks for the local people and (2) susceptibility to fire due to an increase of available fuel. As the ban also fails in tackling root causes that make the land so prone to fire, the ban on fire-clearing as an agricultural tool is a maladaptation.

6. Conclusion

The reality at the local level, and policy making on the national level, are highly disconnected in terms of the Indonesian fires of 2015. Further, the roots of components of the complex set of factors that make Indonesia so prone to fires are inscribed in its recent past. Identification of the dynamics on different scales that have created and will create the current and future situation offers an answer to some whys and hows of Indonesia's fire problem.

The next El Niño phenomenon will certainly happen, and the frequency of the occurrence of extreme El Niño events is predicted to increase due to global warming (Cai et al. 2015). Thus, the Indonesian fire issue is even more pressing. An avoidance of a repetition of the Indonesian fires 2015 is of global significance, as the impact's scope reaches everyone, may it be through positive radiative forcing, economic losses or adverse health effects. However, a ban on fire as an agricultural tool is not the ultimate solution. The given example of a two-fold perturbation shows that the discourse in vulnerability is in need of political approaches that recognize how vulnerabilities arise due to a disconnection of local realities and political measurements, as well as how vulnerabilities are created that constitute the initial situations prone to perturbations.

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CHAPTER VI:

Transnational climate mitigation action in tropical peatlands – implications for smallholder farmers in Indonesia

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Abstract

Peatlands constitute a major terrestrial carbon sink while peat drainage and fires constitute a major source of global greenhouse gas emissions. Formerly considered non-productive lands that need to be drained for the purpose of agricultural production, the protection and restoration of peatlands have recently turned into a major topic in global climate mitigation policies. In particular, tropical peatlands have been targeted by transnational climate action. Little research, however, has investigated how efforts to mitigate greenhouse gas emission from peatlands materialize at the local level and which consequences this entails for the local population. We present insights on this from the coastal peatlands in Jambi province (Sumatra, Indonesia) and use a climate justice lens to evaluate local impacts. We show how in Jambi an increasingly transnational network of state and non-state actors has initiated multiple policies and projects targeting more "sustainable" and "climate-friendly" land use practices on peatlands. However, as these ambitions materialize in new laws, policy programs and land use agreements, local land use rights are reconfigured, gradually limiting local people's livelihood strategies and reducing their capabilities to benefit from their natural resources. Despite the propagation of "win-win" solutions for more sustainable land use, we show how local communities in our case study area lack the opportunity to contribute their perspectives on desirable future developments and are not able to benefit from the proposed low carbon development paths. Instead, local communities increasingly are expected to carry the burden of global climate change mitigation. This occurs through the threefold assignment to protect forests, prevent fires and help restoring degraded peatlands.

Key words: *peatlands; climate justice; climate change mitigation; peat restoration; community based forestry; peat fires; Indonesia;*

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1. Introduction

Peatlands cover only about 3-5% of the Earth's surface, yet store about 30% of global terrestrial carbon stocks (Murdiyarso et al. 2019). The degradation of peatlands through fire and drainage is expected to contribute at least 2 gigatons CO2-eq./yr. or around 6% of global annual greenhouse gas emissions (GHGE) (Joosten 2010, Wichtmann et al. 2016, IEA 2020). This may comprise 12–41% of the GHG emission budget for keeping global warming below +1.5 to +2 °C (Leifeld et al. 2019). Unsurprisingly, the protection and restoration of peatlands has become a central topic in transnational climate mitigation policies. This development presents a major paradigmatic shift for peatland management. Used for agricultural production for centuries, today around 60% of peatlands in Europe are drained (Joosten et al. 2017). In the tropics, large-scale agricultural development of peatlands is a more recent phenomenon closely connected to the expansion of agro-industrial plantations for the production of global commodities (Miettinen et al. 2016, Schoneveld et al. 2019, Olsson et al. 2019, Hein 2019). Estimates suggest that without political intervention, tropical peatland conversion could increase by another 11.6 million hectares and thus dominate global GHGE from peatlands (Leifeld et al. 2019). Multiple studies thus propose to halt this trend (Page et al. 2011, Hooijer et al. 2012, Miettinen et al. 2012, Miettinen et al. 2017b, Leifeld and Menichetti 2018).

While estimates vary across studies, Page et al. (2011) calculated Indonesia to host almost 50% of tropical peatlands. In particular, the expansion of oil palm and pulpwood plantations on peatlands has contributed to Indonesia being the largest global GHG emitter from peatlands (Joosten 2010, Olsson et al. 2019). The first national policies for GHGE reduction from peatlands were introduced under president Yudhoyono (2004-2014) but it was the extremely dry El Niño year of 2015 that brought the peatlands of Indonesia widespread international attention. Just before global climate negotiations in Paris in 2015, large-scale peat and forest fires caused severe environmental pollution, health problems and more daily GHGE than the entire US economy (van der Werf 2015, Harris et al. 2015, Hartmann et al. 2018, Meijaard 2018). Peat protection and restoration became therefore a major target within Indonesia's national climate strategy and has been strongly supported by transnational networks such as the Global Peatlands Initiative and the Climate and Land Use Alliance. It has received climate funding from the US, the UK, and Germany, and civil society organisation like Wetlands International (UK DFID 2016, UN Environment 2016, Wetlands International 2017, GIZ 2020a, Climate and Land Use Alliance 2020).

Yet little research has investigated the consequences of such efforts of peat protection and restoration for local communities living in and around peatlands. Building on qualitative fieldwork and a review of policy documents, we investigate how such national and transnational climate mitigation policies influence the regulatory framework for peatland governance in Indonesia and illustrate their social impacts on the ground. For this purpose, we provide insights from a hotspot of Indonesian peatland restoration programs, the coastal peatlands of Jambi province, Sumatra. Using climate justice as an analytical lens we explore how there the burden of global climate change mitigation is redistributed, involves trade-offs and impacts local people's livelihoods (Klinsky et al. 2016). Particular attention will be paid to perspectives of the most vulnerable groups in the study site as these, like vulnerably people in general, are poorly represented in global climate negotiations (Venn 2019, Walliman-Helmer 2019). Such analysis is particularly relevant in the Global South where peatlands often constitute so-called resource frontiers. These are characterized by highly dynamic land use systems, complex actor landscapes and unstable property regimes making them prone to the production of new social injustices (Peluso and Lund 2011, Sikor et al. 2014, Hein 2019).

The article is structured as follows. First, we reconstruct the emerging role of peatlands in global and Indonesian climate policy. Second, we provide an overview of the recent climate justice literature and its critique of the global climate governance framework. We further introduce the capability approach as an analytical framework for climate justice. Third, we present our methods and then, fourth, turn to our results. We start with an overview of land use history and challenges in Jambi's coastal peatlands and then analyze three recent policies and projects aiming at reducing greenhouse gas emissions from peatlands. We show how these have been pushed trough transnational actor networks aiming at supposedly climate-friendly land use systems and present local people's perspectives as well as evaluations of these interventions. We discuss our insights using the capability approach to evaluate justice implications of these different climate mitigation projects and policies. We round off with a conclusion.

2. Background: peatlands in global and Indonesian climate policy

Peatlands have long been regarded as unproductive land (Maltby 2009). This perspective on peatlands slowly started to change in the 1970s. In 1971, the Ramsar Convention on Wetlands of International Importance recognized, for example, the important role of wetlands for biodiversity. In the mid-1980s, peatlands were then also recognized to provide important ecosystem services such as water regulation and flood retention (Maltby 2009). Initial efforts of protecting peatlands, however, mainly focused on natural, un-drained peatlands. The recognition of peatlands as an important global carbon stock in the past two decades changed this, expanding political ambitions towards peat protection and restoration of drained peatlands under agricultural usage (Joosten, pers. com. November 24, 2019).

The integration of peatlands into global and national climate mitigation policies is a very recent and ongoing process. In 2011, Susan Page famously published a paper emphasizing the importance of including the tropical carbon pool in national and regional GHG assessments. Tropical peat, she estimated, would cover around 11% of global peatland area but 18–25% of the global peat volume, with Indonesia hosting 65% of this alone. As tropical peatlands are estimated to have carbon contents between 50-60% (Neuzil 1997, cit. in Page 2011), drainage which leads to peat oxidation, and peat fires are considered major sources of GHGE (Page et al. 2011, Hooijer et al. 2012, Carlson et al. 2015). Common IPCC guidelines for the reporting and monitoring of GHGE from peatlands were first released in 2013 (Moomaw et al. 2018).

2015 presented a major turning point in climate mitigation policies concerning peatlands, in particular tropical peatlands. Under extremely dry condition caused by El Nino and spurred through the extensive degradation of peatlands, the 2015 fires resulted in the burning of about 26,000 km^2 of peatlands across Indonesia causing large amounts of GHGE (Medrilzam et al. 2017). The fires heightened media, political and scientific attention to GHGE from peatlands and turned peatlands into an important topic at the 2015 Paris Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). In the following, multiple state and non-state actors engaged in the development of climate mitigation action through peatland protection and restoration. The Global Peatlands Initiative founded at COP 22 in Marrakech in 2016 is an example of this (www.globalpeatlands.org). Simultaneously numerous scientific studies as well as NGO reports called attention to the role of peatland degradation for global greenhouse gas emissions emphasizing the need to stop draining peatlands, in particular in the tropics (Greenpeace 2015, Kolka et al. 2016, Osaki and Tsuji 2016, Wijedasa et al. 2016, Wetlands International and Tropenbos International 2016, Evers et al. 2017, Miettinen et al. 2017a, Miettinen et al. 2017b).

Indonesia was among the first countries to commit to reducing GHGE from peatlands. Peatlands were included in the first Indonesian declaration on emission reduction targets published in 2011 (President of the Republic of Indonesia 2010). A moratorium on the granting of new concessions on peatlands was decided the same year and peatland restoration as well as fire prevention were listed as important strategies for emission reduction under provincial REDD+ strategies (PerPres 61-2011, InPres 10-2011, Perbatakusuma et al. 2013). Yet, these initiatives often showed limited effects on the local level. The large-scale peat and forest fires in 2015 largely changed this. Submitted during the height of the fires (September 24, 2015), the Indonesian Intended Nationally Determined Contributions (INDC) to the UNFCCC announced the prioritization of the forest and land use (FOLU) sector in the national emission reduction targets (Republic of Indonesia 2015). At his speech in Paris, the Indonesian president, moreover, announced the plan to establish a peat restoration agency for the first time (BRG – *Badan Restorasi Gambut*) (President of the Republic of Indonesia 2015), which was then founded following a presidential regulation issued on January 6, 2016 (PerPres 1-2016). In the following year, the Indonesian government revised its regulation on the protection and management of peatlands (PP 57-2016) and developed a national plan to restore 2 million ha of peatlands in November 2016[14] (BRG 2016). At the same time national and regional governments in Indonesia further revised and strengthened their policies on the prevention and control of fires (InPres 11-2015, PerMen LHK 32-2016, PerDa Provinsi Jambi 2-2016) and elaborated a development plan for a national strategy for fire prevention (Medrilzam et al. 2017). In total, the Indonesian government pledged that the FOLU sector should account for 87% of the national emission reduction target of the 2020 target and 60% of the 2030 target (Masripatin 2017). As peat decomposition and peat fires alone were estimated to cause 47% of the positive GHGE emission of the FOLU sector in 2016, peatland restoration together with forest fire control therein are to achieve an emission reduction of 230,000 Gg CO2e (Masripatin 2017, Sugardiman 2018). In addition to fire prevention and peatland restoration these emission reduction targets are to be achieved through halting deforestation, afforestation or reforestation, and ensuring a more sustainable forest management, for example through the development of social forestry programs (Perbatakusuma et al. 2013, Direktorat Jenderal Pengendalian Perubahan Iklim 2018). Implementation of all of these policies focuses on specific key provinces with particular rapid peatland conversion, including Riau, South Sumatra, Kalimantan, and our case study region Jambi province.

[14] Later this target was increased to 2,49 million ha which should be restored until 2020 (BRG 2019).

These and other measures are expected to be strongly supported through international climate finance. In its nationally determined contribution to the Paris Agreement (NDC), Indonesia pledged to reduce its national GHGE by an additional 12% by 2030 conditional upon international support, for example through REDD+ (Reducing Emissions from Deforestation and Forest Degradation) - a mechanism aiming to incentivize developing countries to reduce deforestation or maintaining carbon sinks through payments by developed countries (Republic of Indonesia 2016, Masripatin 2017). REDD+ alone is considered to have the potential to reduce land-based emissions by up to 70% (Masripatin 2017). While the Indonesian government to date has only received few payments for results-based emission reductions (Jong 2020) it receives much international financial support in form of policy or project development and capacity building (Masripatin 2017). These are funded through bilateral agreements with countries such as Norway, Japan, Korea, and Germany as well as with international conservation organizations and the private sector (ibid.). Moreover, individual countries, such as the US, England, the UK, Japan, Germany, and the Netherlands have pledged to support specific Indonesian climate mitigation policies such as peatland restoration and fire prevention through their national climate funds (UK DFID 2016, Hansson and Dargusch 2018, GIZ 2020a). Multiple other REDD+ projects, such as social forestry schemes, are funded by the private sector and civil society organisations (Fisher et al. 2018, Enrici and Hubacek 2018, Hein 2019, Shahab 2019).

3. Conceptual framework: justice in the global climate regime

Justice has been a key concern of global climate negotiations since the very beginning in the early 1990s. The UNFCCC guiding principle of "common but differentiated responsibilities and respective capabilities" reflects this (Art. 3, UNFCCC 1992). The implementation of the UNFCCC framework has, however, repeatedly been criticized for not operationalizing justice sufficiently and for making very limited attempts to address global inequality (Okereke and Conventry 2016, Venn 2019). Climate justice scholars have repeatedly taken issue with the strong link between climate change, vulnerability, poverty and marginalization (Schroeder 2010, Raleigh 2010, Shue 2014, Smith and Rhiney 2016,). Despite hardly contributing to global climate change (Hickel 2020), vulnerable people and countries are often particularly strongly impacted by climate change, while at the same time being excluded from decision-making processes in global climate politics (Venn 2019, Walliman-Helmer 2019).

The shift towards a voluntary climate governance framework with the Paris Agreement has raised additional justice concerns. Such concerns are particular raised with regard to distributive justice, which is concerned with the rules that govern a just distribution of social, political, economic, and environmental goods and bads (Schlosberg 2007). By moving away from legally binding emission reduction targets global climate mitigation policies have been criticized for weakening former rules regarding a just distribution of the climate burden (Okereke and Coventry 2016, Falkner 2019). Contrary to the Kyoto Protocol, national voluntary commitments to the Paris Agreement are not negotiated internationally and no framework to assess these in terms of equity exist (Okereke and Coventry 2016, Falkner 2019). On the one hand, this voluntary regime, it has been argued, has resulted in increasing bargaining and pressure on developing countries to reduce their emissions (Hurrel and Sengupta 2012, Ciplet 2015, Okereke and Coventry 2016). Developing countries have indeed been found to commit to ambitious climate action but without subsequently receiving sufficient technological and financial assistance to realize this (Hurrel and Sengupta 2012, Ciplet 2015, Okereke and Coventry 2016, Falkner 2019). Such a climate regime might therefore result in negative impacts on vulnerable communities in particular in case their perspectives are not sufficiently recognized and represented in the development of national climate strategies (Venn 2019, Walliman-Helmer 2019). A lack of recognition and the resulting inequitable participation in political processes are considered key underlying conditions for injustices in the distribution of the global climate burden (Schlosberg 2007). On the other hand, justice scholars have raised concerns about the legally non-binding nature of the NDCs and a lack of common emission reporting requirements. Together, this may result in a mere "'ambition' rhetoric" (Okereke and Coventry 2016: 9) resulting in continuously increasing emissions and thereby further impacting climate vulnerable communities (Falkner 2016, Schoeneveld et al. 2016, Schneider et al. 2019, Rowan 2019).

There is hence a need to analyze the justice implications of post Paris climate mitigation action. In order to evaluate justice in specific climate policies, the capabilities approach developed by Sen and Nussbaum has been proposed (Schlosberg 2012, Forsyth and Sikor 2013, Ribot 2014, Klinsky et al. 2016). The capability approach argues that just arrangements should be judged not only in distributive terms, but also in how those distributions affect people's well-being (Schlosberg 2012). Well-being therein is conceptualized in terms of people's capabilities, which constitute the actions or opportunities (= functionings) that a person can benefit from for their livelihoods (Klinsky et al. 2016). A particular strength lies in its focus on the question whether people are able to the live the life they value and on the actual realisability of people's functionings (Robeyns 2005). A capability thus does not only require a person to posses certain resources, it also requires that a person has access to the personal, social, environmental conversion factors necessary to actually benefit from the resources (Robeyns 2005, Forsyth and Sikor 2013). Therein the capability approach represents a pluralistic and open conception of justice. It is clearly concerned with distributive justice, yet also encompasses recognition and procedural justice, as both are necessary to turn functionings into capabilities (Schlosberg 2012, Ribot 2014, Klinsky et al. 2016). It is this outcome-oriented focus of justice that is considered particularly useful in the assessment of the effectiveness of specific climate policies (Walker 2009, Schlosberg 2012, Ribot 2014, Klinsky et al. 2016,). In conclusion, the capability approach thus asks "what it is that either enables or interrupts a living system in its ability to transform primary goods […] into functionings" (Schlosberg 2007: 30-31).

Applying the capability approach to analyze justice implications of climate mitigation policies requires interrogating the following aspects. First, it needs to question whether people have the political opportunity to contribute their perspectives on the development of low-carbon development pathways (Robeyns 2005, Schlosberg 2012, Forsyth 2015, Klinsky et al. 2016). It then needs to assess if and how climate mitigation action reduces or enhances the people's capabilities (Klinsky et al. 2016). Truly just climate policies, as Klinsky et al. (2016) argue, should not only achieve to prevent the reduction of capabilities but also a just distribution of the benefits and actions aiming at a low carbon development (see also Pottier et al. 2017). Finally, a capability approach to justice demands also that climate politics pursue strong mitigation action in order to prevent the reduction of capabilities due to climate change (Klinsky et al. 2016).

4. Methods

A first short field visit to Jambi's peatlands took place in September 2015. In depth, qualitative field research was then conducted by the first author in 2017 (March-May and December) focusing on the sub-district of Mendahara Ulu. During the three months stay, qualitative research methods were applied in three villages located along the Mendahara River. Semi-structured interviews, informal interviews, participative observation and group discussions were the main methods used. 23 semi-structured and 40 informal interviews as well as two group discussions with villagers were conducted. The interview partners were chosen according to snowball and purposive sampling methods (Flick 2016). At the village level, these included government representatives, heads of farmer groups and other village organizations, farmers of different crops, village elders as well as people that were directly affected by changes in the local governance regime. Several households were interviewed during consecutive visits, combining both formal and informal interview situations. Interviews were triangulated with participative observation, including several visits to villagers' and companies' plantations as well as the neighboring protected forest areas. In addition, the first author participated in a one-day workshop on participative conservation planning in one of the villages.

External perspectives on local developments as well as local and regional policy making were gained through 11 expert interviews in (sub-)district and provincial capital cities (June 2016 – December 2017). These interviews involved representatives from academia, civil society organizations, and different government offices. Finally, the first author participated in two conferences on peat management and restoration: the RSPO Annual Roundtable meeting in Bali (December 2017) which included a workshop on peat management, and a conference on climate protection through peat protection organized by German Ministry for Environment and Nuclear Safety and the Greifswald Mire Centre (October 2018). Interviews in Indonesia were largely conducted in Indonesian language by the first author and partly translated into English by a local student assistant. Formal interviews were recorded and transcribed in Indonesian and together with field notes coded for content using MAXQDA software (Mayring 2000).

An extensive literature review supplemented field work data. To trace and understand regulatory changes in the peat governance framework at national and regional level in Indonesia, the first author reviewed a wide array of grey literature including government reports, environmental legislation, climate policies and other reports as well as websites on the management of peatlands published by the transnational actors involved in governing Jambi's peatlands.

5. Results

5.1. Land use history and current challenges

The sub-district Mendahara Ulu is named after the Mendahara River that drains the Sungai Buluh peat dome (Fig. 1). With a history of roughly 13,400 years of peat development and peat depths of more than 9 m, the Sungai Buluh peat dome is considered a global tropical carbon sink and has been designated a pilot area for peat restoration (Hapsari et al. 2017).

First settlements in the peatlands of Mendahara Ulu were established in the 1970s, when migrants from South-Sulawesi, South-Kalimantan and Java who had initially settled along the coast started moving inland (see also Claridge, 1994, Galudra et al. 2014). These pioneers established tidal rice cultivations in the shallow peatlands adjacent to the Mendahara River. Clearing forests manually in these swampy areas was a difficult and exhaustive exercise. Many of the settlers thus invited friends and relatives from across Indonesia to help. As more and more people settled in the area, land clearing expanded further inland as well as upstream from the Mendahara River, expanding until around 4 km from the riverside and reaching peat depths of more than 3 m. In the 1980s, local residents started to establish coconut plantations which gradually substituted the paddy fields. Fishing and logging constituted further important sources of income. As coconut productivity was low, these plantations were later intercropped with areca nut palms and oil palms, which today constitute the main sources of income for local livelihoods. However, securing livelihoods in the swampy peatlands is a strenuous endeavor, in particular where peat layers exceed 1 m depth. Managing plantations there is much more challenging than on mineral soil (Fig. 2-3). Productivity on peat soils is lower but the costs of harvesting, weed management, and transport of plantation produce are much higher. Moreover, frequent flooding and the high acidity of soils strongly limit the farmer's crop choice. Areca and oil palms are widely considered the only crops that can be profitably cultivated on deep peat soils.

Drainage has always been the basic precondition for agricultural cultivation in the area. Drainage channels serve to demarcate the boundaries between plantations and between village hamlets and also fulfil important functions for transport, fishing and personal hygiene (Fig. 4). The maintenance of the channels constitutes an important part of communal work, with the yearly *cuci parit* (cleaning and dredging of the channels) being accompanied by larger social festivities. Over the past two decades, drainage is largely done by external actors and companies investing in the plantation business in the area and the drainage systems have gradually become professionalized and larger scaled. This, in turn, has resulted in a more rapid drying and subsidence of the peat soil and impacted the use of fire to prepare land for agricultural production. Today peat fires have become hard to control and pose the risk of burning plantations and houses. Under the influence of El Niño in 2015, around 1,500 ha of mainly unmanaged, degraded peatlands burned around our research villages, causing respiratory diseases and economic losses (Fig. 7). Interviewed villagers reported that, in the aftermath of the fires, the productivity of areca and oil palm plantations had decreased by up to 80%.

Ongoing contestations over land are another major challenge in Mendahara Ulu. In 1999, a former logging concession was converted into a protected peat swamp forest area and, in the early 2000s, a forest production concession of more than 70,000 ha was granted to a transnational pulpwood company (Fig. 1). Both, concession and protected forest area were granted at national level without consultation with local authorities and landowners. They also partly overlap with villager's plantations (Fig. 1, other land use) resulting in numerous land conflicts between private concession holders, local communities and state authorities. Irregular land sales to absentee investors further fueled such conflicts.

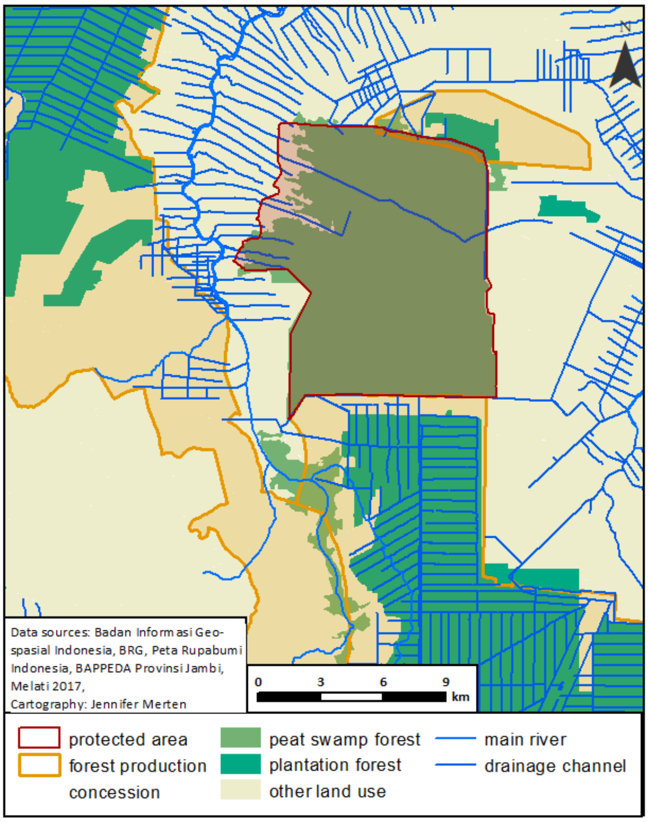

Fig. 1: Study area. The category "other land use" mainly includes small- and medium sized plantation systems.

Fig. 2 and Fig. 3: Tilted areca and coconut palms on strongly subsided peat soils

Fig. 4: Drainage channel in one of the studied villages.

5.2. GHGE and a changing governance regime of peatland management

The recognition of Jambi's peatlands as a major source of GHGE added further constraints for local landowners in our case study area. In particular, three developments to reduce GHGE from peatlands contributed to this.

5.2.1. Reducing emissions through community based forestry?

The first was the development of a social forestry project. Social forestry schemes have been developed by the Indonesian government as a mechanism to solve existing land conflicts through granting local communities land use rights on state forest land (Fisher et al. 2018, Resosudarmo et al. 2019). They are also considered a major strategy for GHGE reduction within national and provincial REDD+ strategies and are thus also being developed on forested peatlands (Indonesian REDD+ Taskforce 2012, Perbatakusuma et al. 2013,). The implementation of such schemes is often carried out by civil society organizations as local governments often lack the financial and human resources for this (Royer et al. 2018).

Our study area is an example of this. There, WARSI, a local NGO involved in the provincial REDD+ process started to develop a social forestry project in 2010. The project aimed to develop models of sustainable peatland management and help the communities to solve a land conflict about villager's plantations that are located inside the boundaries of the protected peat swamp forest area. This was to be achieved through establishment of three village forests (*hutan desa*), a land use permit category which grants communal land use rights in the protected area (Fig. 1). It was funded by the US based Climate Works Foundation who aim to support a "low carbon emission development" through strengthening community based peatland management (Climate and Land Use Alliance 2019, Climate and Land Use Alliance 2020). The foundation receives corporate funding from, inter alia, Hewlett Foundation, The David and Lucile Packard Foundation, Margaret A. Cargill Foundation, IKEA foundation, Ford Foundation as well as public funding from Norway's International Climate and Forest Initiative (Climate Works Foundation 2020).

In 2018 the last of these three village forest was legally established. While members of WARSI were proud about this achievement and argued that the village forest permit had improved the communities' land rights, the villager's perspectives were a different one. The new land use permit only included the right to use ecosystem services, for example through the development of tourism or the harvesting of non-timber forest products such as honey. Previous activities such as logging or the cultivation of plantation crops was forbidden. Already existing plantations were tolerated for the current plantation cycle, however, maintaining drainage channel was, as elsewhere in the forest, forbidden immediately. Most villagers thus did not see much benefit in these new land permits and complained about heavy land use restrictions. A villager expressed his surprise as follows:

> We can plant whatever we want, but we cannot cut the wood. How then should the plants grow? If they are planted under the dense cover. [...] And especially if we are not allowed to dig drainage channels, to make the water flow out, how should they live?" (former village head, May 3, 2017)

Others got angry about the land use restrictions on their existing plantations:

> Please, have a protection forest; [...] there is nothing wrong about it. But what is already there [the plantations] don't disturb it. [...] The land that my father opened in 1980, the land that I opened, if they touch it, I am ready to fight. (smallholder farmer owning land inside the protected area, May 24, 2017)

The social forestry project also led to conflicts within the village between those supporting and those rejecting the project. A farmer who owned land inside the protected forest area explained that he would not join WARSI's meetings, as he feared doing so would upset his friends who feared losing their land due to the village forest project.

These diverging views can partly be explained with a partial and incomplete participation of the villagers in the project development. Participation in project workshops was often limited to the elaboration of specific activities inside the forest area with no room to change the land use regulation of the protected forest area. The suggested benefits of the village forest for many villagers remained largely opaque. While WARSI praised the use of ecosystem services and non-timber forest products, the villagers did not really understand the concepts and listed oil and areca palms as ecosystem services during a workshop visited. Cultivation of these, however, was not allowed under the land use permit. The lack of knowledge regarding marketable tree products from allowed peatland tree species and missing market structures for these products resulted in the villagers not taking these land use options serious. An experimental planting of jelutung trees (a natural rubber variety), for example, by some was referred to as a mere reforestation strategy (*penghijauan*) due to the missing market for this kind of rubber produce. Even villagers proactively engaging in the project remained sceptical about future income opportunities. Clearly proud to protect a forest of so-called global importance, as they put it, they invested a lot of work in the establishment of forest boundaries, drainage blocks and experimental tree plantings (Fig. 5). They benefited from working with the NGO and public authorities through, for example, attending capacity building workshops across the country. However, they had not received any income from their work and questioned why there was so little support by the government.

Finally, the willingness of villagers to engage in the project was lowered further by a general mistrust in the government. As the government had previously taken away land rights, many people remained sceptical that their newly granted rights were permanent.

> "Now I am still allowed [to manage my plantation], because the oil palm is still productive. But the people have to ask about the perspective, how will it be in the future? Will the people still manage the land, or will it become protection forest again? [...] In the year 2000s the government already took back the land [turning it into a protected area]." (smallholder farmer owning land inside the protected area, May 1, 2017)

Fig. 5: Experimental tree and crop planting inside the protected forest area.

5.2.1. New regulations on the prevention of peat fires

The second development affecting local land use rights was the implementation of new regulations and policies concerning the prevention, control and monitoring of fires, which were developed in the aftermath of the 2015 fires. Both a national strategy and regional government regulation on fire prevention were supported by climate funding by the UK and the German government (UK DFID 2017, Santoso, 2017, Medrilzam et al. 2017, GIZ 2020a, GIZ 2020b, CIFOR 2020a, CIFOR 2020b). Within the project "Sustainable Forest and Peatland Management to Reduce Emissions" the UK Climate Change Unit, for example, spent £ 3 million from April 2016 to March 2018 through the Indonesian Climate Change Trust Fund (ICCFT) with the aim to restore degraded peatlands and to reduce fire hotspots in six Indonesian provinces, including Jambi, by 20% (UK DFID 2017). For this purpose the ICCFT supported the provincial government in Jambi to develop stricter regulations on fire prevention and management (UK DFID 2017). Similarly, the German government supported the development of "forest fire prevention policies at national, provincial and district levels" (GIZ 2020a) within the Forests and Climate Change Programme (FORCLIME) whose objective it is to "reduce greenhouse gas emissions from the forest sector while improving the livelihoods of Indonesia's poor rural communities” (GIZ 2020b).

Two regulatory changes were of particular relevance for communities in our study area. First, a complete ban on fire for land clearing and land preparation activities concerned the villagers. In the past smallholders were allowed to clear land smaller than 2 ha by using fire (UU 32-2009; art. 69-2), but this was changed by a government regulation prohibiting the use of fire on peatlands (PP 71-2014) and strengthened further by a new provincial regulation on fire prevention banning fire on any kind of land (PerDa Provinsi Jambi 2-2016). This complete ban conflicted with traditional practices of land management. In particular, food crop farmers lamented that fire was necessary to maintain soil fertility:

> Here, if you want to plant paddy, because the soil is not fertile, you have to burn it first, the grass. […] to decrease the acidity. […] But now, [...] there is the regulation that we are not allowed to burn the land anymore. (village head, March 28, 2017)

Providing alternative land clearing methods to fire was part of the national and regional regulations, yet training and infrastructure were hardly provided in the villages visited. A small excavator provided by the sub-district government promised little relief for the farmers. It could only be rented to each village every couple of years, was too small to remove larger pieces of wood and could only be used on areas with overlapping land claims (see Fig. 1). Several interview partners complained about the ban and recommended that the government should distinguish between fires:

> If we gather everything [the wood], we can burn the land. [...] If you want to clear two hectare land […] then you should clean it [the borders] [...] or make a small channel, so that the fire cannot pass it. [...] The government only says we cannot use fire [...] But they don't provide us with the technology. How shall the people make a plantation, if they are not allowed to burn the land? They should give instructions to the people: this is the way you can burn your land. (village government representative, May 23, 2017)

Second, they were concerned about the increasing involvement of military and police in the prevention, monitoring and control of fires (PerMen LHK 32-2016, PerGub Provinsi Jambi 31-2016). The villagers were generally supportive of a stricter control and prevention of peat fires as the large-scale peat fires in 2015 had clearly traumatized them. However, the villagers and also key informants interviewed in Jambi city considered the regulation too repressive. Across the province, public banners announced that disregarding the ban on fire could result in imprisonments of up to 10 years (Fig. 6). In addition to law enforcement, the national strategy on fire prevention in fact recommended a strengthening of social institutions and community participation in fire prevention. Yet, the only form of participation realized at the village level was the establishment of so-called village fire brigades, whose tasks included awareness raising, patrolling and reporting fire to the police. Together, the strengthened involvement of police and military, the heavy punishments and the village brigades resulted in a situation where people were clearly frightened to start fire:

> When the police was not yet involved [...] the people were still brave to burn the land, but since the police [is involved], they will directly be detained. [...] In the past the police did not have the authority for that [...] But since 2015, after the big fires here, the police was involved. Now they

watch the hotspots and as soon as they see a fire spot, they will come. Even if people only burn their garbage, they will come. (representative of the sub-district government, May 22, 2017)

Food crop farmers, who were not provided with alternative land preparation techniques, in consequence were observed to give up on their cultivations:

Some time ago there was a big fire […] so I called the police and the man was detained. […] He burned the land to plant chilli. He had to make a statement, that he would never burn land again. [...] But after that he never planted chilli again. (member of a village fire brigade, April 9, 2017)

Fig. 6: Public banner warning people about the risk of prison sentences in case they set fire.

5.2.2. Transnational efforts for peatland restoration

The third development revolves around changes in the institutional and regulatory setting of peatland management in Indonesia as the national government aimed to restore more than two million ha of degraded peatlands across the country. The 2015 fires and the Paris Agreement were major drivers behind this. The national peatland restoration agency (*Badan Restorasi Gambut*) (BRG) in charge of this restoration receives climate funding from the governments of Germany, Norway, South Korea, the USA, Japan, the UK and the Netherlands (UNOPS 2018, Hansson and Dargusch 2018, BRG 2019, UK DFID 2019, GIZ 2020a,). Moreover, the BRG collaborates with a broad number of international organizations, development consultancies and research institutes including the Climate and Land Use Alliance, Global Green Growth Institute, Euroconsult Mott MacDonald, the World Resource Institute, The United Nations Environment Program, the World Wide Fund for Nature (WWF), Wetlands International, and the Greifswald University (van Paddenburg 2017, Greifswald Moor Centrum 2018, BRG 2019, Kopansky 2019, Kieft 2020, Mott MacDonald 2020, Simon & Warta 2020, Wetlands International 2020, WRI 2020). All of them publicly commit to reducing GHGE through sustainable peatland management. The estimated sum of international funding for peatland restoration activities via the BRG is at least around 125 million USD (Hansson and Dargusch 2018, BRG 2019).

The restoration plan builds on a threefold strategy of rewetting, revegetation and revitalization (= increasing community welfare) and aims to foster community participation in these restoration activities (brg.org.id). Beforehand, the BRG mapped peatlands across the country, designating areas for protection (defined as peat deeper than 3m[15]) or for cultivation, and identified peatlands with a need of restoration activities. In Jambi province, peatland needing restoration covered 409,000 ha, or 66% of the province's peatland area (BRG 2016). In Mendahara Ulu almost all peatlands were defined as in need of restoration (Fig. 7).

At the time of research, the restoration work focused on the protected peat swamp forest area, where canal blocks were installed and paludiculture demonstration plots were established. Paludiculture is an agricultural system that aims at cultivating traditional peat plants not requiring drainage (Wichtmann and Joosten 2007, Wichtmann et al. 2016). It is considered the main strategy to increase community welfare in peatland restoration areas (BRG 2016). A few farmers volunteered to participate investing many uncompensated working hours but most villagers considered it strange that the restoration agency wanted people to stop drainage. According to the villagers, drainage increases land productivity, yet the restoration agency tried to convince them otherwise:

> Since I was small I managed plantations, my father, my grandfather and I managed plantations. There is no story about a crop that would grow without drainage channel. They will not grow in the water. What should grow there? (village government representative, May 23, 2017)

Some people were open to such trials but admitted that if production would be lower than with drainage, other villagers would probably not follow their example. A scientist interviewed shared this concern noting that it was highly uncertain whether paludiculture was a viable income alternative to existing plantations.

The plan to conduct peatland restoration activities on villager's land outside the protected forest area was another source of concern for many villagers. Most of the villagers' land in the study area is defined as cultivation zone but should not be drained lower than 40 cm below soil surface. This would require the closing of large drainage channels used for transportation:

> Here, everybody uses small boats; there is nobody who uses a four-wheel drive. So automatically, if we cannot clean the drainage channels, how shall we get out our plantation produce? (smallholder farmer, May 24, 2017)

In general, activities by the restoration agency remained ad hoc and not well coordinated. A key informant involved in the activities argued that state money for the restoration agency had only been released in the second half of 2017. In consequence, the installation of drainage blocks remained poorly planned and resulted rather in a redirection of water flows than in their interruption (Fig. 8).

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[15] In fact, peat soils deeper than 3 m were already classified as protected areas since 1990 (Keputusan Presiden 32-1990). Despite this and due to a lack of public data on peatlands, deep peat areas were often targeted for economic development programs by national and regional authorities in the past.

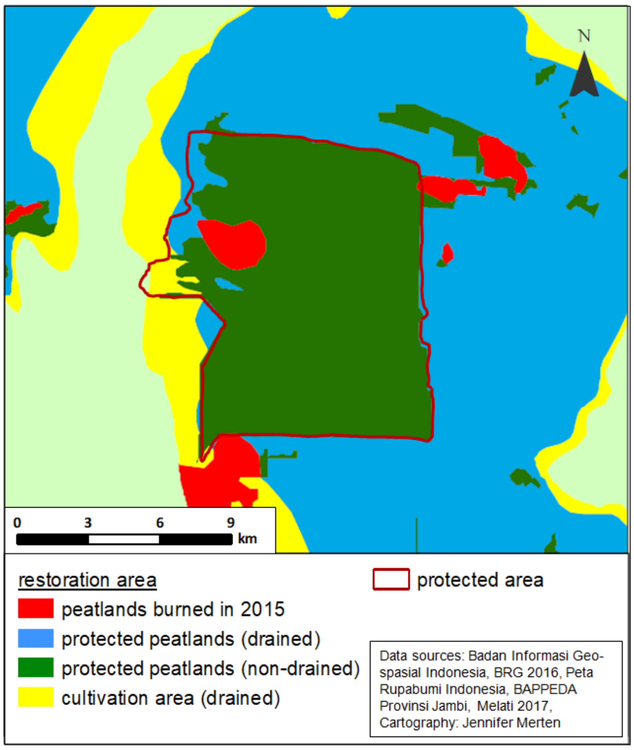

Fig. 7: Peat restoration area.

Fig. 8: Dried peat showing a failed attempt to stop drainage with a canal block.

6. Discussion

Shaped through global climate negations and transnational climate action peatland management in Indonesia has undergone a paradigmatic shift over the last decade. Formerly considered a resource for plantation development, Jambi's carbon-rich peatlands are increasingly turning into a global site of carbon sequestration and emission reduction. Covering an area of 671,600 ha of which 89% have turned into a source of carbon emissions due to fire, drainage or conversion into plantation systems this is not surprising (Miettinen et al. 2016, Miettinen et al. 2017b). Politicians, scientists and civil society organizations are increasingly propagating a more "sustainable" and "climate-friendly" use of peatlands that builds on the restoration and conservation of peat soils as well as peat swamp forests. In Indonesia, as elsewhere in the Global South, the use of peatlands has become an increasingly international question (UN Environment 2016, Dargie et al. 2018, IUCN 2020). Programs and projects in Jambi such as the social forestry project or a new provincial regulation on fire prevention involving organizations such as the British Department for International Development (DfID), the German Agency for International Cooperation (GIZ) and the Climate Works Foundation illustrates this.

Most policies and projects aiming at a more climate-friendly use of peatlands in Indonesia are clearly committed to core justice principles such as community participation, the strengthening of land use rights or increasing community welfare (BRG 2016, UK DFID 2019, GIZ 2020a, Climate and Land Use Alliance 2020). Analyzed with a capability approach to climate justice, our results, however, highlight that most climate actions fail to comply with important components required for truly just climate mitigation projects. First, a capability approach to climate justice requires that the affected people have a political opportunity to contribute their perspectives on the development of low-carbon development pathways (Schlosberg 2012, Forsyth 2015, Klinsky et al. 2016). Meeting such principles of procedural justice is not only necessary in terms of guaranteeing a just development, but is also considered crucial to successfully achieve climate-friendly land use scenarios (UNFCCC 2010, cit. in Enrici and Hubaeck 2018, Minang et al. 2015). Despite this, numerous studies show that projects aiming to reduce land-based emissions often lack good plans for involving local communities, following instead top-down project impositions (Bottazzi et al. 2014, Leach and Scones 2015, Fisher et al. 2018, Hein 2019). The case of peatland conservation and restoration in Jambi mirrors this. Despite opposite visions of development between communities, who consider drainage and fire a precondition for agricultural activity, and international donors, who propagate the rewetting of peatlands, few attempts have been made to reconcile these positions. Although villagers' needs, for example, were assessed during NGO-led conservation planning workshops, neither the NGO nor the communities had the power to change the restrictive land use regulations that strongly limit local land use options. In addition, while villagers argued for a differentiation of fire types, the promised participation in fire prevention policies mainly concentrated on policy implementation, such as fire monitoring and extinction. This lacking recognition of the villager's perspectives and an inequitable participation in the design of climate mitigation policies has caused supposedly inclusive policies such as fire prevention or community based forestry to be misaligned with local needs and aspirations, something other land-based mitigation projects also suffer from (Bottazzi et al. 2014, Afroz et al. 2016, Corbera and Schroeder 2017, Fisher et al. 2018, Hein 2019,). Instead of empowering local communities, such projects have elsewhere in Indonesia been analyzed as a means for the state to share the burden of forest protection (Royer et al. 2018), a point also relevant in our case.

Second, the capability approach demands climate policies to avoid the reduction of capabilities of those most vulnerable. The explored case of climate mitigation from peatlands, however, suggests that the exact opposite has happened. The combination of different projects and policies aiming at reducing GHGE from peatlands in Jambi have resulted in the reconfiguration of local people's land use rights to make these correspond with climate mitigation targets and have greatly reduced their capabilities of benefiting from their land. Securing livelihoods has ever since been a difficult endeavor in the swampy peatlands of Mendahara Ulu. Limited crop choices, costly plantation management and low productivities constitute only some of the daily challenges of smallholder peatland farmers there. Instead of enhancing the capabilities of these people, new climate mitigation projects and policies further constrain these. A capability, for example securing one's livelihood, as Sen (1992) emphasized, requires a person to have access to the personal, social, environmental conversion factors necessary to benefit from their land. The combined effect of the ban on fire, the prohibition of maintaining drainage channels inside the protected forest area and also the general mistrust in the national government have eroded these. Today, many villagers in our study area are concerned about what they should do with their land as they lack knowledge and the financial as well as technical capacities to adopt alternative land use practices, not to mention state support to do so. This insecurity is even threatening local food security. In Mendahara Ulu, as in other parts of Indonesia, a ban on fire together with economic and environmental risks makes farmers convert their food crop cultivations into perennial tree plantations (Vel et al. 2016, Hartmann et al. 2018, Merten et al. 2020). Equally, farmers may not be willing to invest in the management of their plantations, if future land use regulations remain unclear. Instead of being involved in the development of alternative land use scenarios, vulnerable communities are thus increasingly subjected to state-imposed land use restrictions with their rights being conditional upon particular forms of livelihood as well as conservation outcomes (Li 2002, Afroz et al. 2016, de Royer et al. 2018). Land use rights in our case study region are gradually limited. On top of that, the allowed forms of livelihoods are expected to contribute to the development of low carbon development pathways. In sum, it appears that villagers in our study region are increasingly expected to carry the burden of global climate change mitigation. This supports climate justice scholars' concerns that the voluntary climate governance of the Paris Agreements could contribute to production of new injustices in the burden-sharing of the global mitigation burden (Hurrel and Senupta 2012, Ciplet 2015, Okereke and Coventry 2016, Falkner 2019). In Jambi, this materializes through the communities' threefold assignment to protect forests, prevent fires and help restoring degraded peatlands.

Third, the capability approach demands climate politics to achieve a just distribution of the benefits related to a low carbon development (Klinsky et al. 2016, Pottier et al. 2017). As international climate discourse is increasingly framed in terms of green development and win-win solutions, climate justice advocates urge the use of such opportunities to enhance the capabilities of the most vulnerable in society (Klinsky et al. 2016, Pottier et al. 2017). Indeed, the policies and projects for climate-friendly use of peatlands in Jambi were all legitimized accordingly. None of the promised benefits have, however, materialized in our study area. Land clearing and preparation without fire has not become an accepted method due to the lack of knowledge and technical as well as financial capacities among smallholders. Experimenting with different tree crops and land use systems is certainly a reasonable way of exploring more climate-friendly land use options. However, experimental plantings alone are unlikely to contribute to widespread shifts in established land use systems. As in other REDD+ project areas, establishing economically viable land use alternatives to lucrative export-oriented plantation crops is difficult and appears even more difficult on rewetted peat soils (Sills et al. 2014). Smallholder farmers in our study region have never built their livelihoods on the collection of forest products or agroforestry systems, complicating their acceptance of these proposed land use alternatives. Paludiculture propagated as a solution for a sustainable agricultural use of peatlands equally remains contested. Most paludiculture projects are still in the experimenting phase. Yet already, low product prices, value chain barriers and long return-on investment periods were shown to be challenges for achieving economic viability, also beyond our study area (Tata 2019, Ward 2020, Budiman et al. 2020). Even in Europe, where pilot projects have been developed since the 1990s, paludiculture remains difficult to upscale due to a continued lack of substantial carbon offsets (Schaller et al. 2011, Wichtmann et al. 2016, Wichmann 2017, Hermanns et al. 2017, Ferré et al. 2019, Ziegler 2020).

Fourth, a capability approach requires climate politics to pursue strong mitigation action in order to prevent the reduction of capabilities (Klinsky et al. 2016). Following the Paris Agreement, the Indonesian government has, conditional upon international support, adopted highly ambitious targets regarding reducing GHGE from the land use sector and peatlands. Yet, such achievement remains highly questionable in our study region. Although the villagers had reported to be afraid of setting fires, due to strict law enforcements, renewed peat fires in the studied villages in 2019 show the limited success of fire prevention policies (NASA FIRMS n.d.). Across Indonesia the 2019 fires burned nearly 10,000 km^2 and reached GHGE similar to those in 2015 on individual days (Jong 2019a, Jong 2019b, Haniy et al. 2019). This is not surprising. Multiple studies have warned that a simple ban on fire will largely remain ineffective. In particular, knowledge gaps on causal relations between ignition sources and fires and the lack of attention towards powerful economic and political interests behind the fires are considered main reasons for this (Tacconi and Vayda 2006, Vayda 2010, Purnomo et al. 2017). Equally doubtful remains the success of carbon emission reduction in peatland restoration. The results of this paper, obtained in a priority area of peatland restoration, suggests hardly any restoration success by the end of 2017 when, according to the peat restoration plan, in fact 50% of the restoration target should have been achieved already (BRG 2016)[16]. Our findings showing only small-scale restoration trials with limited rewetting success are similar to other studies across Indonesia. These have show that such trials together with little previous experience with tropical peatland restoration, a complex hydrology, and conflicting land use demands hinder successful peatland restoration and large-scale emission reduction (Ritzema et al. 2014, Dommain et al. 2016, Dohong et al. 2018, Uda et al. 2018, Olsson et al. 2019, Budiman et al. 2020). Water level monitoring by the peat restoration agency exemplifies the limited success of ongoing rewetting experiments, with online data showing widespread water tables more than 1m below the peat surface during dry season in 2020 (https://sipalaga.brg.go.id/, August 10, 2020). Finally, it remains doubtful that villagers owning land inside the village forests will contribute to a reforestation of the area. The lack of social legitimacy of proposed alternative land use scenarios in Jambi goes along with high expectations regarding government support in finding alternative, economically viable land use options. If this does not come, alternative land use systems such as paludiculture are unlikely to succeed. Again, similar concerns have been raised in other social forestry projects, where contestations over state enclosure of community land or the failure to incorporate local land management practices in forest management were considered substantial risks to conservation outcomes (Fisher et al. 2018). As climate mitigation success across all three policies and projects thus remains doubtful, our results contribute to concerns that voluntary national climate commitments may rather consist of a rhetoric of ambitions than of actual emission reduction (Okereke and Coventry 2016, Rowan 2019).

7. Conclusion

Climate change mitigation remains a pressing issue and reducing greenhouse gas emissions from peatlands is key to achieving this. Smallholder farmers in Indonesia's coastal peatlands are facing multiple challenges to secure their livelihoods. Risks of fire and floods as well as low plantation productivity on degraded peatlands constrain their daily life, while the ongoing drainage of peatlands constitutes a significant source of GHGE. Transnational climate efforts for a more sustainable use of peatlands, however, have not managed to solve this dilemma. On the contrary, top down policy development has further reduced smallholder farmers' capabilities to benefit from their land. While

[16] In fact the Nationally Determined Contributions submitted by Indonesia only pledge a restoration of 2 million ha until 2030 and set much lower restoration targets for 2016 and 2017. However, the recent issuance of regulation by the Minister of Environment and Forestry (P.10/2019) raises serious doubts whether the set target for peatland restoration will be seriously continued by the Indonesian government. The new regulation has strongly watered down many previously set land use restrictions in peatlands and only requires the protection and restoration of "Peat Dome Peak" in a legally-binding manner (Eyes on the Forest 2019).

supposedly alternative land use scenarios such as the use of ecosystem services or paludiculture do not yet provide alternative sources of income, law enforcement to control fires, logging and drainage pushes their current land use practices to the brink of illegality. Despite these and an unclear success in terms of greenhouse gas reduction, Indonesia's program for peatland protection and restoration receives much technical and financial support from transnational state and non-state actors. As long as such policies do not strive for true community empowerment and lack solid research documenting and monitoring emission reduction success, they risk not going beyond a rhetoric of ambition while marginalizing already vulnerable communities even further.

Author contributions

Jennifer Merten: Conceptualization, Methodology, Investigation, Validation, Formal analysis, Writing - original draft, Writing - review & editing. **Jonas Østergaard Nielsen**: Writing - Review & Editing. **Rosyani**: Writing - Review & Editing. **Heiko Faust**: Writing - Review & Editing.

CHAPTER VII: SYNTHESIS AND CONCLUSION

This thesis has explored the ongoing social and environmental transformation processes in the context of agrarian change for global commodity production in the Global South. Its focus lies on the transformation of hydro-social relations and the production of risk and inequality therein.

Building on a historically-situated case study approach, this thesis provides in-depth insights from one of the fastest changing landscapes in the Global South, the lowlands of Jambi province, Sumatra, Indonesia. There, I conducted 10 months of fieldwork in two distinct physiographic settings. I have further complemented insights gained from this fieldwork by building on interdisciplinary collaborations with colleagues from the natural sciences. Together, we discussed a wide array of ecohydrological measurements and data. Building on both social and natural science data, this thesis sheds light on both locally specific as well as overarching transformation processes contributing to the production of new water risks in Jamb province.

Thereby, this thesis provides substantial insights into a rather neglected research topic in the context of agrarian change, namely water. Conceptually, it adds to ongoing debates on how to integrate social and natural science perspectives in a geographical and political ecology-inspired study of environmental risks. In the following, I will work out some conclusions drawn across the different articles and manuscripts presented in chapters II-VI of this thesis. They comprise key findings relating to the thesis' objectives and the research questions guiding fieldwork. In addition, I will outline major scientific contributions to different bodies of literature, first on an empirical and then on a conceptual level.

1. Synthesizing empirical findings and contributions

1.1. The socio-natural production of water risks

In order to understand the transformation of hydro-social relations in Jambi, in a first step, I questioned if and how water flows in Jambi province have changed during the past decades. For this purpose, I have explored rural villagers' perceptions and evaluations of environmental change. I have then complemented these assessments with ecohydrological measurements and data. Together with my natural science colleagues, I have thereby added to current investigations of the ecohydrological consequences of large-scale forest and land use conversion into plantation systems.

In Jambi province, as we have shown, agrarian change has come along with significant alterations in local water flows. These alterations present multiple and interrelated water risks that are of social and political relevance at both local and global levels. In particular, a development towards more extreme situations was of great social concern across the different research sites. Villagers had noted that river and groundwater levels, today, are increasing much faster during the rainy season and are decreasing much faster during the dry season than this had been the case about 20 years ago. For the interviewed villagers this change has resulted in risks of flooding and water scarcity. Analyses of streamflow data and groundwater measurements (chapters II and III) largely support the villagers observations. They show high fluctuations in streamflow and groundwater levels in plantation systems and point to lower dry season water levels in oil palm plantations, compared to rubber plantations and forest reference sites. Increases in flood events of a large lowland river provide further support for an increase of flood risk in Jambi's lowlands (chapter III). In the province's coastal peatlands, higher fluctuations in water levels were not only of concern due to the risk of flooding and water scarcity, they also entailed the risk of fires (chapters V-VI). There, the large-scale drainage of peat soils causes water levels to decrease rapidly during the dry season, resulting in large areas of highly flammable dried peat. Peat fires are not only of local, but also of global importance. Releasing large amounts of greenhouse gas emissions, the fires also contribute to global climate risks (chapters V-VI, cf. Hooijer et al. 2012, Wijedasa et al. 2016, Miettinen et al. 2017). Finally, across chapters II-IV, I have shown that the a deteriorating water quality of surface waters was discussed as another important development associated with the recent agrarian change across all study sites.

My colleagues and me then interrogated the specific biophysical and social processes behind the production of these water risks (chapters II-IV). By explicating the interaction between social and ecohydrological processes in the alteration of water flows, chapters II and III provide practically relevant and socially sensitive recommendations regarding land use and flood management in Indonesia. As outlined in chapter III, the linkages between land use conversion and water flows are highly contested among both social and natural scientists. This thesis adds to this literature by providing a locally specific and empirical evidence for such linkages. Increasing extremes in river and groundwater levels in Jambi province emerge from multiple interacting ecohydrological changes and social developments: in chapters II and III my colleagues and me have analyzed the role of different biophysical processes behind the changing water flows. Our results show that the combined effect of alterations in transpiration rates and soil hydraulic properties following forest conversion are likely explanations behind increasing extremes in water levels. In chapters III and IV, we have further analyzed the role of social developments in altering water flows: We found that a continuous expansion of plantations and villages into wetland areas result in increasing technical interventions in water flows, which increase and redistribute floodwater at the local level.

Finally, I also investigated how framing and discourse about water have contributed the risk-laden nature of hydro-social relations in Jambi province today. The thesis thereby adds to literature investigating the interactions and feedback processes between social and natural processes in the production of environmental risk. It shows how mutual changes in material water flows, people's cultural attachments to water and their material and discursive practices of engaging with water provide key explanations for the production of water risks in Jambi. Chapter IV has illustrated how agrarian change in Jambi has engendered a representation of flooding as an environmental hazard. It finds that actors involved in the plantation business emphasize water as an obstacle to economic development. Local notions of river flows as dynamic, seasonal rhythms, on the contrary, are increasingly marginalized. This development is further strengthened through alterations in the material properties of water flows. Water pollution and rapid increases in river water levels undermine traditional practices of using water and coping with its risks. The discursive shift in the framing and representation of water helps explain an ongoing alteration of water flows as well as an augmenting and unequal vulnerability to flooding among Jambi's people. Local representations of flooding as a hazard influence the ways how flooding is managed. They hence contribute further to ever increasing technical interventions in water flows and thus to an unequal distribution of flood damage.

1.2. The socio-natural production of social inequality

In addition to disentangling the multiple processes contributing to the production of water risks in Jambi province, this thesis also discusses the social impacts and dynamics these risks evoke. Thereby, it adds insights into important social dynamics in the context of agrarian change towards global commodity production, so far hardly touched upon in literature. As I have shown across chapters II-VI, the social impacts of the newly produced water risks are varied across social groups and touch upon different livelihood dimensions, such as the economy, personal health and social security, to mention only a few. Yet, a number of overarching themes and findings are worth highlighting more specifically. They illustrate path dependencies as well as feedback processes and reveal developments contributing to the production of social inequality and injustice.

First, the newly produced water risks are greatly diminishing smallholder access to land**.** As described in the introduction to this thesis, access to land remains crucial for people in Jambi to secure their livelihoods (McCarthy et al 2012, chapter I: 3.3). Previous studies on this matter emphasize the importance of people's ability to acquire formal land titles, their access to authorities or their ability to engage in resistance movements in order to secure their access to land (e.g. Kunz 2016, Beckert 2016, Hein 2019). This thesis, exemplifies how access to land, i.e. the capability to benefit from it, also depends on the environmental condition of that land.

The villagers interviewed for this thesis reported that environmental conditions, such as flooding but also climate, have become hard to predict. This change complicates their planning and management of agricultural fields and plantations. The difficulty in predicting environmental conditions adds to the observed extremes in both a scarcity and an excess of water. Together, they often result in a decrease of crop productivity or even lead to complete harvest failures. In degraded peatlands, the impacts of these developments are even more severe: there, flooding may last for several months and water scarcity may result in fire that burns entire fields and plantations. As a result, the capability to cultivate food crops has decreased in all study regions. Food crops, as I have shown, are those crops particularly vulnerable to water scarcity or flooding. In addition, longer periods of flooding also affect rubber plantations grown near rivers. Crop choice is thus increasingly limited to a crop known to resist even the harshest environmental conditions: the oil palm. Throughout chapters III, IV and VI, I have shown that most interviewed villagers describe the oil palm as a particularly robust crop. It is known to defy flooding, water scarcity, wind and may partly even recover after fire. By working out this widespread understanding of oil palm as a particularly robust tree crop, this thesis also contributes to a better understanding of smallholder crop choices. Beyond profitability (Clough et al. 2016, Grass et al. 2020) and agro-economic management characteristics (Feintrenie et al. 2010, McCarthy et al. 2012, Schwarze et al. 2015), it presents environmental change and crop specific characteristics as additional reasons behind the widespread adoption of oil palm cultivation among smallholder farmers in Indonesia.

Second, this thesis suggests that water has turned into a much contested resource in Jambi province. Water both reflects and deepens social inequalities at local and global level. In addition to contestations over access to land and forest (e.g. Steinebach 2008, Li 2014, Beckert et al. 2014), it demonstrates how struggles about access to and protection from water have turned into additional sources of social contestation and inequality in the context of agrarian change in Indonesia. Existing risk mitigation strategies and policies, tend to exacerbate these dynamics further.

Alterations in local water flows in Jambi are largely related to forest conversion towards intensively managed plantations (chapters II-IV). Forest conversion has altered local ecohydrological functions and has required large-scale draining and flood protection of land. Responsibility for flooding, water scarcity and fire, accordingly, is often attributed to companies and investors converting forest areas at a large scale. In addition, risks of flood damage or health impacts due to polluted water sources are distributed highly unevenly across society. The case of flooding in chapters III and IV shows how financial and technical means enable certain actor groups to redirect water flows from their land, thereby often aggravating flood damage on adjacent plantations. In addition, social inequality is exacerbated further through more indirect pathways. The decreasing quality of surface waters together with problems of water scarcity is threatening local water supply (chapters II and IV). Village programs to improve water supply are under way in many villages visited. Yet, at the time of research, the financial means to purchase bottled water or drill deep wells were largely decisive for a household's access to safe water. Consequently, poorer households are often highly vulnerable to health threats from the use of polluted water sources.

Chapter VI has added to this by showing how water has also become a contested resource at the international level. In this chapter, I have shown how numerous international state and non-state actors aim at the mitigation of climate risks through the promotion of more "climate friendly" land use systems in Jambi's peatlands. As this vision of development clashes with local approaches to land use and water management, contestations about opposing land use imaginaries emerge. While powerful transnational actor networks manage to shape land use policies and agreements in Jambi's peatlands, smallholder farmers lack the social recognition and the means of political participation to do so. Such newly issued land use restrictions often lead to a further marginalization of vulnerable peat farmers and food crop farmers in particular (chapters V and VI). This thesis thereby adds to a growing body of research that illustrates the transnationalization of environmental conflicts and resource governance. It shows how contestations of water management in Jambi's peatlands are not only conflicts at local level; they are equally conflicts about questions of burden sharing with regard to the mitigation of global environmental change.

Third, in this thesis I argue that wetlands constitute those sites where such contestations and social dynamics materialize most strongly. I thereby contribute to emerging research that depicts wetlands as a highly contested development frontier in Indonesia (Hein et al. 2018). This thesis adds to the existing literature by working out the variety of channels and initiatives through which transnational climate action contributes to local land use contestations in this frontier region. In addition, this thesis works out how wetlands are also sites of social differentiation, which adds further to such contestations.

As shown in chapters III, IV and VI, profitably managing wetlands is much more challenging than securing one's livelihood on mineral soils. It requires costly investments in the construction of roads and drainage channels. Many farmers, who do not depend on these lands financially, thus tend to sell them to more well-off actors. In areas where both mineral and wetlands exist – and farmers may hence chose which land type to buy – this leads to a social differentiation between landowners: poor landowners, who cannot afford more suitable land, farm in direct neighborhood to landowners who see wetlands as an attractive investment opportunity. Together, the transnationalization of peatland governance and a social differentiation at the local level thus exacerbate the production of social inequality in Jambi's peatlands. Farmers who are already vulnerable to floodwater redirected by neighboring agro-industrial plantation complexes suffer from new land use restrictions imposed with the goal of "sustainable" land use development.

2. Conceptual and methodological contributions and reflections

In addition to the empirical findings, I have demonstrated how critical realism and relational dialectics provide well-suited conceptual frameworks enabling a more integrated study of environmental risk. On a methodological level, I have examined different ways of integrating local ecological knowledge, obtained through qualitative interviews, with scientific measurements. Thereby this thesis also contributes to the field of geography more generally. It provides valuable findings regarding an integration of human and physical geography, both conceptually and methodologically. In the following, I will present critical reflections on these approaches and work out key contributions to the literature.

2.1. Conceptual reflections on an integrated analysis of environmental risk

A strength of both, critical realism and relational dialectics, is that they seek to openly explore and reconstruct the multiple processes that have contributed to empirically manifesting risk conditions. Yet, they do so in very different ways. A critical realist approach to risk production aims at studying the interaction of social and environmental processes by integrating different knowledge areas (Bhaskar 2010: 4f). A relational dialectical approach conceptualizes nature as a socio-natural hybrid and focuses on analyzing the mutual constitution of meaning, materiality, discourse and practice (Swyngedouw 2004: 18f).

In a retrospective, I argue, that critical realism is a particularly well-suited philosophy to integrate the complexity of biophysical processes within a political ecology-inspired analysis of risk production. This is due to the fact that critical realism, compared to relational dialectics, offers a philosophy of science more easily acceptable on part of the natural sciences. Moreover, critical realism allows collaborations between the social and the natural sciences to take place on eye-level because it treats all knowledge areas as equally valid. Another strength of critical realism is that it enables pragmatic ways of knowledge integration, where conceptual or theoretical integration is not achievable or not aimed at.

A relational dialectical approach to risk analysis has the advantage that it allows for a better and deeper understanding of what actually constitutes a "hazard". In chapter IV of this thesis, I have used this approach to work out the materially and discursively produced and thus hybrid nature of flood hazards. Such kind of analyses, I argue, present important add-ons to political ecology and other social science studies that tend to treat hazards as external forces only (e.g. Rebotier 2012, Simon 2014). Moreover, a relational dialectical perspective allowed me to elaborate on the cultural-symbolic dimensions of flooding, something that is equally less developed in literature, both in political ecology and risk research more generally (cf. Baviskar 2003, Acharya 2015, Donovan 2017).

Yet, the main advantage of a relational dialectical approach to risk analysis, I contend, lies in its dialectical thinking. Through its focus on the tensions, contradictions and reciprocal adjustments between humans and nature, it provides for a much more dynamic perspective on risk than critical realism does. It thus presents a particularly strong approach to the study of feedbacks, interactions and path dependencies in the production of environmental risk. Thereby, such dialectical thinking also helps explain how environmental risks may turn into systemic qualities of socio-natural relations, not only in Jambi but also beyond (cf. chapter IV).

Within this process of mutual adjustment, a relational dialectical perspective on risk also provides space to elucidate the role of the biophysical environment in shaping social relations. Yet, the engagement with the biophysical materiality within studies employing a relational dialectic approach to nature, is often a rather superficial one. Due to the emphasis on the non-neutrality of socio-ecological change, these studies typically strive to explain the production of unequal and/or contested socio-ecological conditions in their analysis (cf. Harvey 1996, Swyngedouw 2004). Hence, their ultimate interest lies on the question how social relations are interwoven in transformations of the biophysical environment (cf. also chapter IV). This focus also reflects in the fact that key scholars, propagating a relational dialectical approach to the study of nature, and water in particular, remain curiously silent about how to integrate the biophysical environment methodologically.

Qualitative research may well help to identify physical forces as drivers behind social relations. However, it may not interrogate causal processes behind physical events and processes, such as flooding. This clearly requires the integration of natural science methods in analysis. The understanding of nature and water as a socionatural hybrid, however, seems irreconcilable with the natural sciences. This is because these rely on a positivist epistemology taking things as objectively measurable. In consequence, this contradiction leaves important methodological questions unanswered regarding the study of hybrid socio-nature. In chapter II of this thesis, I have challenged this apparent incompatibility. Together with my colleagues, I have illustrated how a relational dialectical study of water may achieve a deeper integration of the biophysical environment in practice. By building upon natural science methods, we have unveiled how soil degradation and oil palm transpiration rates are key forces shaping conditions of water scarcity in Jambi. On top, we use the lens of hybridity to work out the political dimensions of water scarcity. One way of reconciling positivist research methods and socionatural hybridity theoretically may be through an integration of an awareness of the social construction of science into risk analysis. Critical realism, which acknowledges that all knowledge is socially constructed and partial (cf. Forsyth 2003), presents a way of doing so (cf. chapter I: p. 10) . Yet, more explicit elaborations on these theoretical reflections are needed in order to provide thorough guidance on how biophysical processes can be integrated better in a relational dialectical approach to risk.

2.2. Methodological reflections on knowledge integration

Chapters II and III of this thesis build on an integration of local and scientific knowledge in order to interrogate potential causal processes behind empirically observed changes in local water flows. Practically integrating these knowledge areas, however, was often a challenging endeavor. A main challenge therein was to integrate qualitative social science and quantitative natural science methods. In what follows, I hence want to discuss and reflect on a number of common arguments, challenges and preconditions for knowledge integration across the social and natural sciences.

Researchers mainly relying on quantitative research methods often have reservations against the use of qualitative research methods (cf. e.g. Strang 2009, Spiller et al. 2015, Wesselink et al. 2017). Relying on local people's perceptions and evaluations is often depreciated for only providing "subjective interpretations" and qualitative research methods for lacking "hard data and numbers". Integrating local people's perception and knowledge with scientific measurements at a first glance thus appears more straightforward if building on quantitative research data from household surveys. I want to counter this assumption by presenting a number of benefits of integrating qualitative social methods with natural science measurements. First, qualitative social research provides a perfect starting point for problem-oriented, interdisciplinary research endeavors. It allows to openly explore, which processes of environmental change are of greatest relevance for local communities and for what reasons. Second, it may provide valuable insights into the social dynamics of environmental change. Certainly, any claim about environmental change will be influenced by the interview partner's personal background, context and experience. Yet, if staying in the field for longer periods, a researcher may learn to interpret both interview statements and the social context of the interview partner. Such contextual and experiential knowledge may then provide insights into the socially differentiated impacts of environmental change or the social and political contestations about it. Such insights are highly relevant for providing socially sensitive policy recommendations (cf. e.g. Forsyth 2003). Finally, local ecological knowledge obtained through qualitative interviews may also push natural science analyses. Many interview partners in Jambi showed to have a good general awareness of environmental processes and interconnections, for example between soil compaction and flooding. Surely, they will not be able to evaluate the exact contribution of specific ecological processes to environmental change. Yet, as they build their knowledge rather at landscape than at plot level (Usher 2000), their knowledge may draw attention to additional processes influencing water flows, such as climate change or gold mining.

It has also been questioned whether short-term interdisciplinary research endeavors may achieve research findings that go beyond the sum of individual knowledge areas (e.g. Conelly and Anderson 2013, Krueger et al. 2016). I argue yes, and this even in the case of a paper-focused, a posteriori integration of fundamentally opposing datasets. An integrated research design right from the start would be the ideal. Yet, this is not always possible, was not always thought upon initially or is hindered by the need to submit research proposals before getting to know the research site in-depth. Even an imperfect knowledge integration may push scientific analysis in different ways. Knowledge integration may, for example, contribute to different types of analysis. In the development of chapters II and III, new data was obtained and analyzed (e.g. river discharge), different analyses were conducted (e.g. seasonal patterns) and data was analyzed from different viewpoints (e.g. water scarcity). An a posteriori integration of different disciplinary knowledge areas most probably cannot establish definite causal relations between the different processes. This may be the result, for example, of lacking data or a mismatch of scales. However, it may provide indications supporting or rejecting initial hypotheses. These may help identify research needs for previously neglected environmental dimensions of agrarian change. Finally, as I show in this thesis, such knowledge integration may also provide for practically relevant research findings, such as the need for soil protection or a better monitoring of flood control infrastructure.

Such knowledge integration, however, requires a number of preconditions regarding researchers and research environments. Most importantly, working across the social and natural sciences requires mutual respect, a true open-mindedness towards different epistemological cultures among the researchers and a good degree of perseverance (cf. also Danermark 2019, chapter I: 4.7). It is time-consuming, challenging, at times frustrating and requires constant self-reflection of the own modes of doing research. A minimum understanding of the different research traditions is thus indispensable. Looking back, it certainly helped a lot in this regard that several of the co-authors involved in chapters II and III were trained in geography. Despite this, clearing out all doubts and concerns about the other research approaches was certainly not possible. The need to pursue individual PhD or PostDoc-projects hardly allowed for an in-depth engagement with the different epistemologies and research traditions alongside our paper-projects. Such engagement, however, could have certainly pushed knowledge integration much further. Hence, I strongly recommend graduate programs and interdisciplinary research projects to push interdisciplinary training of young scientists. In addition, if interdisciplinary collaborations are aimed at, more time is needed to complete a PhD study. The work on chapter III of this thesis took one and a half years from the decision to write a joint paper until its submission to the journal *Ecology & Society*. In particular, bottom-up research approaches may end up highly time-consuming. The more open a research approach begins, the more processes potentially influencing the research topic will appear, thus complicating the choice of subsequent data analyses. The work on chapters II and III of this thesis thus resulted in long discussions about what datasets and analyses to include and which people to involve in our work. We spent innumerable hours trying to acquire additional datasets (e.g. on river sedimentation) or to find new ways of analyzing data (e.g. a remote sensing analysis of riparian vegetation). Many of these ideas yet ended up being discarded. Nevertheless, the researchers involved in the end agreed that the achieved output was certainly worth these efforts. In the end, both chapters presented more complete and socially sensitive insights into the production of water risks in the context of agrarian change for global production, a fact that was also valued by the reviewers assessing the manuscripts.

Ultimately, treating both natural science and social sciences on eye-level is another challenge in a paper project. The risk of leaving one side as a subordinate, service-providing knowledge area (cf. also Spiller et al. 2015), was something I was confronted with constantly. Decisions about which journal to choose, which statement to highlight or how many words to allow for each dataset, were always difficult acts of balance. In addition, finding scientific journals that are well equipped to handle the review process of interdisciplinary papers is difficult. A team of only two reviewers may not be able to review a paper adequately, if different disciplinary methods are combined. In our case, this resulted in the fact that some of the data presented in chapters II and III were hardly addressed in the reviewers comments.

After the publication of chapter II, we hence discussed whether or not two separate articles, one natural science and one social science article, would have better done justice to the methods and efforts of the different scientists involved. Yet, we concurred in our conclusion that without the aim of publishing a joint paper, the other involved PhD students and me might then not have continued working together. The reason for this assessment again rested on the limited time frame of a PhD project.

3. Outlook and research needs

In this thesis, I have extensively explored the dynamic, contested and risk-laden nature of hydro-social transformations in the context of agrarian change in Indonesia. Yet, there remain several research topics on which I could touch upon only briefly in this thesis. Hence, I want to provide some final insights into research topics that emerged during my field research and that I consider to deserve more in-depth attention in future research.

Across the different chapters of this thesis, I have repeatedly illustrated that the expansion of plantation systems often competes with existing food crop cultivations. Flooding and water scarcity often pose the risk of harvest failure of food crops. In addition, a number of further developments make farmers give up on their food crop cultivations. These are, inter alia, economic disincentives, a high labor demand of food crops and an increasing amount of pests in monoculture plantation landscapes (cf. also Merten 2014, Otten et al. 2020, Vel et al. 2016, Lakitan et al. 2018). Together, such conditions have contributed to a continued decrease of local food production in Jambi province (Jambi Provincial Government 2016). In response to this decrease, the Indonesian government has introduced numerous policies on food sovereignty and security in recent years (cf. Vel et al. 2016). During field work, I found that those policies aiming at an expansion of plantation systems and those aiming at ensuring food security were competing at the local level. Food crop cultivation in Jambi in fact has turned into a highly contested topic. During my field research, I have, for example, come across newly issued district-level regulations that prohibit the conversion of food crop fields into plantations. Not surprisingly, these were strongly contested among food crop farmers. However, I also observed villagers using their plan to cultivate food crops as an argument to justify land claims towards plantation companies. Finally, on another occasion, I heard government officials argue that the cultivation of wet rice could present a "sustainable" version of using peatlands, although this would require partly draining the peatlands. How different actors invoke different imaginaries of land use, and the local dynamics these evoke, would provide for much more interesting research. Among others, it could add insights into existing research on competing state projects (cf. Hein et al. 2018) as well as research on land use competition and changing food regimes (Niewöhner et al. 2016).

Oil palms, as I have shown across chapters II-VI, appear to be a truly robust crop, relatively easy to cultivate and hardly influenced by harsh environmental conditions such as flooding or pests. It hence remained the primary crop choice among smallholder farmers at the time of field research. However, a number of interview partners also mentioned that they were considering replacing oil palms in the near future. In coastal areas, some people deemed areca nuts more promising than oil palms. Others reported about a project that aimed to convert former oil palm cultivations into food crop fields. Whether the specific characteristics of oil palms contribute to their long-term cultivation or whether volatile world market prices and increasing sustainability requirements make farmers and companies reconsider their crop choice, remains unclear. Research from other areas in Southeast Asia has shown that crop choices may change within short times frames (e.g. Hall 2011, Friis et al. 2019). At the present time, oil palm plantations need to be replanted in many places across Jambi province as productivities of older palms are decreasing. It presents a perfect timing to investigate whether oil palms will remain the favorite crop choice in Indonesia and what we can learn from the farmers' decisions with regard to boom-and-bust cycles of export-oriented cash crops.

A research topic that I pursued initially during my field research was the investigation of village- or district-level initiatives for a more sustainable land use development. Though not reflecting in their crop choice (cf. Clough et al. 2016), many villagers are well aware and concerned about an environmental degradation in monoculture plantation landscapes. During field research, I was told about multiple village-level plans to replant trees along the river side, protect forest areas around natural springs or about other small-scale nature conservation measures. Yet, at the time of research, few of them had been realized, requiring a follow up on such projects. Such research could contribute to understanding under which conditions local initiatives for more sustainable land use are realized and which actors play a key role therein.

Field research also revealed that village authorities differ strongly in their ability and their power to influence local (land use) development. In particular, villages with good road access have become attractive for land investments by absentee investors and have experienced rapid in-migration during past years. Such processes seemed to limit village authorities in their ability to shape local development. One village head, for example, claimed that he hardly knew who lived where and who owned which land. Such dynamics also appeared to decrease social cohesion and community work. "Less developed", more distant villages in contrast showed much lower social inequalities and less social conflicts. A higher social cohesion in these villages also resulted in a socially more just and environmentally more sustainable way of managing land use. This manifested, for example, in a much lower occurrence of peat fires compared to neighboring villages. More in-depth studies on the regional heterogeneity in land use and social developments could thus provide valuable insights into the limits to and conditions for more sustainable land use development.

Last but not least, there remains a need to follow up on the recent policies and projects aiming to push alternative, low carbon developments on peatlands. Initial government plans for mitigating greenhouse gas emissions from peatlands targeted at a large-scale peatland restoration and severe land use restrictions. A recently issued regulation by the Minister of Environment and Forestry (P.10/2019) yet appears to partly revoke these ambitious plans. It aims at implementing peatland restoration rather on individual peat domes than on a landscape level (Eyes on the Forest 2019). It thus remains to be seen, whether climate mitigation action on Indonesian peatlands will go beyond individual restoration projects. This will not only be relevant in terms of smallholder's land use options but also with regard to the success of global climate negotiations.

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APPENDIX

1. Appendix to chapter I: Introduction

a. Interview guidelines for the first and second field visit

Interview guideline for farm households

Household characteristics

1. Where were you born? What ethnic group do you belong to?
2. When did you move to this village?
3. Why did you move to this village?
4. When you first moved to this village what crops did you cultivate?
5. When you first moved here, how much land did you own? From whom did you buy it?
6. Did you change the crops you cultivate since you first moved here?
    a. If yes, when did you change the crop? Why did you change it?
    b. Who in the family decides what crop to cultivate?
    c. Did anybody outside of your family influence you to cultivate that crop?
    d. Did you buy or sell land since you moved here?
        i. If yes, from whom did you buy it?/To whom did you sell it?
7. Today how many hectares do you own of which crop?
8. What kind of land certificate do you have? Does that apply to all of your land?
9. Do you have any other sources of income? (Animals, business...)
10. Are you part of any group, institution, association in the village?
11. Are you involved in the village government?

Village development

1. What do you think have been important positive developments in the village?
2. What do you think have been important negative developments in the village?
3. How do you think will the village change in the future?
4. What do you think are most important things that need to be improved at village level?
5. What group or institution do you consider most important for village development?
6. Is there any specific person you consider especially important for village development?
7. Is there any person or group working specifically on the environment?
8. Is there any person or group that tells people where they can plant which crop?
9. Do you think this village is different to other villages in the surrounding? *Please explain*
10. Do you think the society in this village is different to other villages in the surrounding? *Please explain*
11. Did you perceive any environmental changes in the village level?
12. Did you perceive any changes in the quality of the land in the village?
13. Do you think the village has any problems related to the environment?
    a. How do you think they could be solved them? Who do you think is responsible to solve them?

Plot management

Ask specifically for each agricultural crop grown (e.g. rubber, oil palm, paddy)

1. Do you own land at one location only or do you have different plots?
2. What management activities do you perform on your plantations?
3. How did you learn how to manage your plot? *If not understood: e.g. friends, training….*
4. Did you receive any training?
5. Do you wish to get more training on a certain topic?
6. What are most important challenges for you in your plantation management?
    a. What would you need to overcome these?
7. Do you manage the whole plantation in the same way or are there any differences?
    a. If yes, why?
    b. If yes, is that important to you?
8. If there is more than one location:
    a. Do you manage all plots the same way?
    b. Are there any differences in the plots regarding the site conditions? *(e.g. soil, water, topography)*
        i. If yes, is that important to you*? If no specific answer: Do you manage these sites differently? Does that impact the productivity of your plants?*
9. If the crop was changed in the past: Did you perceive any changes in the quality of your land after you changed crops?
10. If no crop change: Did you perceive any change in the quality of your land during the last years?
    a. If yes, what do you think has caused that?
    b. What impact does that have for you? (*positive/negative)*
    c. If negative impact: Do you think there is anything that you could do to improve that problem?
11. Is there any law/regulation that influences what crop you cultivate? If yes, which one?
12. Is there any law/regulation that influences how you manage your land? If yes, which one?
13. Is there any person/group that influences how you manage your land? If yes, who?
14. Are there any local values/adat rules that influence how you manage your land?
15. Did you experience any changes in the productivity during the last years? If yes, do you have an explanation for it?
16. Do you know about certification systems of oil palm? *If no answer, ask specifically for ISPO or RSPO*
17. Do you know farmers that manage their plantations differently? If yes, what do they do differently? Do you know, why they do this?
18. If you need to replant your crop, do you think you will change the crop?
    a. If yes, why?
    b. If no, would you change anything in the management of the crop?

Riparian sites

1. Is there any river or swamp area on your land? *If yes:*
    a. Is that area somehow important to you? *If no answer:*
        i. Do you do fishing there? If yes, did you observe a change in the fish population? If yes, why?
        ii. Do you use the water for anything?
        iii. Do you think this area is important for your plantation? *(e.g. for the productivity of the crop, for the environment (e.g. biodiversity)?)*
    b. Do you manage the area next to river or swamp differently from the rest of your land? If yes, why?

c. Did you observe any changes in this area during the last years?
    i. If yes, do you have an explanation for this change?
    ii. Do you think this change is reversible? If yes, how?
2. Is flooding an issue in your plantation? *If yes,*
    a. Did the flooding have an influence on your crop choice?
    b. How does the flooding that impact your productivity?
    c. Does the flooding influence your management of your plantation?
3. Do you think, rivers, swamps or flooded area should be differently managed?
    a. If yes, why?
4. Do you think there is any impact from you plantation to the water resources? *If yes, please explain*

Water supply & sanitation

1. Where do you get your water from?
2. What do you do with your waste water?
3.

ADDITIONAL QUESTIONS *(if time allows)*

Plot management:

1. Do you work on your plot by yourself or does anybody help you?
    a. If somebody else works on the plot: Who is that? (family, labour)
2. Do you apply fertilizer in your plot?
    a. If yes: How often? Which type of fertilizer?
3. Do you apply pesticides in your plot?
    a. If yes: How often? Which type?
4. Do you weed your plantation manually?
5. Do you keep animals in your plantation?
    a. If yes, which? How many? Why?
6. Do you perform any other management activity on the plot?

Households characteristics

12. How many years did you go to school?
13. How many people live in this household? When were they born?
14. What is the occupation of the other household members?
15. Do you think people will still be growing oil palm in the future?

Interview guideline for representatives of village organizations

Background/structure of the group/organization

1. When was the organization found?
2. Do you know, why the organization was found at that specific time?
3. How many people work in this organization?
    a. Did the number of members increase or decrease during the last years?
    b. If yes, do you have an idea why the number of members changed?
4. How is the structure of your organization?
    a. How are leaders selected?
    b. How are decision made?

Work scope of the institution

1. Can you please explain me about the work of your organization?
2. What focuses do you have?
3. How do you work?
4. With whom do you work?
5. What are current important projects?
6. With which other institutions do you cooperate at village level?
    a. How? How often?
    b. Which cooperation are especially important to you?
    c. How do you work together with the village government?
7. With which other organization do you cooperate outside of the village? *(also incl. district government etc.)*
    a. How? How often?
    b. Which cooperation are especially important to you?

Work experience

1. What were very successful projects?
2. Did you ever have projects that could not be completed?
    a. If yes, do you know what difficulties were at that time?
3. What do you think are most important topics for the people in the village (regarding your work)?
4. What are most important challenges for you?
5. Does the village government somehow control, support, regulate your work?
6. What laws do you consider important for your work?
7. Are there any laws that make you work more difficult?
8. Are there any issues that would need a new law?
9. Is there anything from the village government that could be done to make your work easier?

Village development

14. What do you think have been important developments in the village?
15. What do you think have been important positive developments in the village?
16. What do you think have been important negative developments in the village?
17. How do you think will the village change in the future?
18. What do you think are most important things that need to be improved at village level?
19. What group or institution do you consider most important for village development?
20. Is there any specific person you consider especially important for village development?
21. Was that different 10, 20 years ago?

22. Is there any person or group working specifically on the environment?
23. Is there any person or group that tells people where they can plant which crop?
24. Do you think this village is different to other villages in the surrounding? *Please explain*
25. Do you think the society in this village is different to other villages in the surrounding? *Please explain*

Interview Guideline for representatives of the village government

Village Characteristics

Can partly be obtained elsewhere (e.g. village statistics)

1. When was the village founded? Why? By whom?
2. How was land use characterized at that time? How did that change (develop) over time?
3. How many people lived in the village when it was found? How many people live in the village today?
    a. Did the village grow gradually or was there any special event/year when many people came?
4. How is the current proportion of ethnic groups here? (Javanese, Sunda, Batak, Orang Rimba…)
    a. If there are Orang Rimba: How many of them live in the forest and how many in the village?
5. How many hectares does the village land comprise?
    a. Is there any private company on the village land?
        i. If yes, what kind of company? What is the name of the company
        ii. If yes, how many hectares belong to the company?
    b. Is there any protected forest in the village?
        i. If yes, how many hectares belong to the protected forest areas?
6. What is the current proportion of different crops in the village? (e.g. oil palm/rubber/forest/fallow land/jungle rubber/paddy/horticulture/ other crops)
7. What is the current proportion of people planting oil palm/rubber/forest/jungle rubber/paddy…? (or mixed)
8. Are there many people that plant fruit trees in the village?
9. Are there any plans for new companies to buy village land?
10. Is there any land that belongs to the village (community)?
    a. If yes: What are the plans for this land for future? *(e.g. convert, protect, rehabilitate forest….)*
11. Is there any land that belongs to the state?

Spatial planning

1. Did you observe any important changes in the environment in your village during the last years?
    a. If yes, what do you think has caused this?
    b. What could be done to improve that?
2. Is there a spatial plan for the village?
    1. If yes:
        i. How was it elaborated?
        ii. Who was involved in the elaboration?
        iii. From which year is it?
        iv. What were priorities during the elaboration?
        v. What does it regulate? (crop? protection? River? Forest? Agricultural inputs?)
    2. If not:
        i. How do you decide who can grow which agricultural crop in what area?
        ii. Is there any local regulation regarding this topic?
        iii. Is there any other regulation regarding the use of natural resources in the village? If not mentioned yes, ask specifically for water, soil, forest, peat land, swamp areas

3. Is there any management of the groundwater at village level?
    1. How many depot air are there in your village?
    2. Is there any regulation about how much water they can sell?

Village development

1. What have been most important developments in the village during the last years?
2. What are most important current developments/projects at village level? (positive and negative)
3. Is there any topic which, according to your opinion, might create problems for the village or the villagers in the near future? (*that is not a problem yet)*
    a. If yes, how do you think these can be prevented?

Village groups and organizations

1. Can you please list up village organizations and groups important in this village? And give a very short description of their work.
    a. If not mentioned yet, ask specifically for:
        i. Groups associated to Mosque/Church
        ii. Farmer groups (oil palm/rubber/padi)
        iii. Farmer cooperatives
        iv. Women/family groups
        v. Youth groups
        vi. NGOs
        vii. Universities/research institutes
        viii. Customary institutions
        ix. Political parties
        x. Extension workers (alone or in group?)
        xi. Any group or person working on certification?
2. Can you please list up any organizations /groups/companies working in the village (but based outside the village)?
3. With which organizations/groups does the village government work together?
4. With which organizations/groups do you personally work together?
5. On which topics do you work together with the District or provincial offices/ministries?
6. Are there any organizations/groups that you consider very important regarding social-economic topics?
7. Are there any organizations/groups that you consider very important regarding environmental topics?

Mapping of the village

1. Can you please draw a map of your village?
2. Can you please tell me a bit about the local physical conditions of the village? – *If possible, draw a map*
    a. Do you know the soil type in the village? Is it everywhere the same?
    b. Is there peat soil in the village? If yes, where?
    c. How is the topography of the village?
    d. Are there any river in the village?
    e. Are there any large swamp areas in the village?
    f. Are there any natural springs in the village?

Specific questions for Kepala Adat

1. Can you please explain me:
    a. How do you work?
    b. On what?
    c. What are main differences to Kepala Desa?

2. What role does customary law still play in this village?
    a. On what topics?
    b. Who uses it?
3. What customary institutions/groups do exist at village level?
    a. What do they work on?
    b. Since when?
    c. How many people are working on it? Who?
    d. Do they work together with other institutions at village level?
    e. Do they work together with institutions outside of the village?

b. Interview guideline for households owning land on riparian sampling plots

Household characteristics

16. Where were you born? What ethnic group do you belong to?
17. When did you move to this village?
18. Why did you move to this village?
19. When you first moved here, how much land did you own?
    a. From whom did you buy it?
    b. What did you grow there?
20. How many hectares of land do you own today?
    a. What kind of crops do you grow on your land?
    b. How many plots do you own?
21. Do you have any other sources of income? (Animals, business...)
22. Are you part of any group, institution, association in the village?

Riparian sites

<u>Plot description</u>

1. How large is your kebun where our research project has its installation?
2. Since when do you own this land?
3. From whom did you buy/get that land?
4. Why did you choose this special location?
    a. If they bought it because it was cheap: how much is the price difference between land in flooding areas in land in non-flooded areas
5. How was the land was used before you bought it?
6. Do you know why the other person sold that land?

Our research project is interested into your plot because there is some influence of water in your plot. Can you please describe how the water influence/flow changes over the year?

1. What is the impact of that to your plantation? Positive/negative
    a. What is the impact for your harvest?
        i. Can you still harvest the plantation?
            1. Do you have any other sources of income if you cannot harvest the plantation?
        ii. How much does harvest decrease if flooded?
    b. What is the harvest that you can get from these plots (per hectare, dry/rainy season)?
        i. If flooding changed, how much does the harvest differ from the past?

    c. What is the impact for your management? Do you treat this plot differently than your other plots?
2. Did you know about the water (problem) when you bought the land?
3. Did you observe any changes in the water body/flow since you bought the land?
    a. If yes, how would you describe the change?
    b. Dulu when did flooding occur (which month), today when?
    c. So what was different dulu? How did you use your land? How did you arrange your life with flooding? Did you have any other activity/income during flooding time?
    d. Since when did it flooding change?
    e. Why do you think it changed?
        i. Do you think it is because perubahan iklim (hujan) or land use change/parit?
        ii. I ever heard that floods are "god given", what do you think about it?

Adaptation to flooding

1. How do you try to live with the flooding. Is there anything that you can do to sustain your income?
2. What do you think should be done to improve your problem?
3. Did you ever think about selling the land?
4. What plant is suited best to (flooded) land like yours?

Generalization

1. Are there many plantation with water characteristics like yours?
2. Why is that?
3. Do they face the same problems as you?
4. What do they do to adapt to it?
a. Who are they?
    a) Where are they from?
    b) Since when do they live here?
    c) What do they grow on that land?
    d) Do they own land somewhere else?
    e) Do they have further sources of income?
    f) Did they ever try to sell the land?

Plantation Management:

1. How old are the trees/palms grown on your plot?
2. Do you use fertilizer of pesticides on your plots?
    a. Which one? How often? How much? Is that every year the same?
3. How much and how often do you harvest? Dry season/rainy season?
4. What animals have you observed on your plot? (birds, mammals)
    a. Do you think this is different to other plantations? (also insects)

2. Appendix to chapter II: Water scarcity and oil palm expansion

Appendix 1. **Detailed method description.**

Methodology of Social Study

The research stay in Indonesia comprised a period of three months in total. An initial two week one-to-one course of Bahasa Indonesia added up on prior autodidactic learning and provided the researcher with a good basic knowledge of the Indonesian language. This knowledge as well as several meetings with our Indonesian counterparts at the Agricultural University of Bogor and the University of Jambi helped to prepare the field research and to get important insights into the Indonesian culture. Except for two expert interviews in Bogor, all interview activities were conducted in Jambi province during a period of eight weeks from May to July 2013. All interviews were conducted in Bahasa Indonesia with the help of an Indonesian research assistant who had extensive prior research experience and a very good knowledge of the English language. Initial participants for household interviews in the village were chosen based on their relevance for the research topic, e.g. length of time lived in Bungku. Subsequent interview partners were chosen by the snowball sampling method (Schnell et al. 2013), aiming to represent the social structure of the village hamlets. Focus group discussions were conducted with groups of six independent oil palm farmers to gain insights into local attitudes and concerns regarding oil palm cultivation. All interview activities were audio-recorded and written down in form of detailed chronological protocols in English language. Data processing and analysis followed the principles of a qualitative analysis of content (after Mayring 2002). Additional personal profiles of the interview partners allowed for an empirical typification (Kluge 2000) of the participants.

Methodology of Climate Change Analysis

We used the Standardized Precipitation Evapotranspiration Index (SPEI), which takes into account precipitation and potential evapotranspiration, to determine drought conditions. Using the Global SPEI database (SPEIbase, Vicente-Serrano et al. 2010), which offers information about SPEI at the global scale with a 0.5 degrees resolution and monthly time resolution, we evaluated drought changes from 1900 until 2011 in Bungku area (E 103.25, S 1.25). The SPEIbase is based on monthly precipitation and potential evapotranspiration from the Climatic Research Unit of the University of East Anglia (CRUE TS 3.2 dataset). Additionally, we analyzed air temperature and rainfall data from 1991 to 2011 from the meteorological station, property of the Indonesian meteorological service (BMKG), located at the Airport Sultan Thaha in Jambi. Rainfall was recorded daily, while temperature was manually recorded three times a day (7, 13 and 18 h). Daily average temperature was calculated by double counting the measurement at 7 am (to consider the lower temperatures during the night) and averaging it with the temperatures measured during the rest of the day. Daily minimum and maximum temperatures were also recorded. Data series were separated into its time components in order to detect possible changes in their trend over the period of study.

Methodology of Environmental Measurements

Evapotranspiration

The eddy covariance technique (Baldocchi et al. 2003) was used to measure evapotranspiration (ET) in a 12-year old oil palm plantation in Indonesia. In the oil palm plantation (S1.693 E 103.391, at approximately 25 km from Bungku, Fig. 1), a 22 m high tower, equipped with a sonic anemometer (Metek uSonic-3 Scientific, Elmshorn, Germany) to measure the three components of the wind vector and an open path carbon dioxide and water analyzer (Li-7500A, Licor_Inc, Lincoln, USA), was running from March 2014 until December 2014. Evapotranspiration fluxes were calculated using the software EddyPro, planar-fit coordinate rotated, corrected for air density fluctuation and quality controlled (Meijide et al., in preparation). For this analysis, ET was estimated using data from three sunny days during the period of July-August 2014, using daytime (6 am-7 pm) data, in order to avoid possible measurement errors as a consequence of low turbulent conditions during nighttime hours.

Transpiration

To derive transpiration rates, we used the thermal dissipation probe (TPD, Granier, 1985, 1996) method to measure sap flux density (*SFD*) in leaf petioles of oil palms and in the trunks of dicottrees. For oil palm, 16 TDP sensors (1.25 cm length) were installed on the underside of oil palm leaf petioles on four palms of varying height per plot (see Niu et al. 2015 for details). For forest and rubber plots, two sensors were installed at breast height in the North and South, respectively, of six (rubber) or eight (forest) tree trunks per plot (2.5 cm sensor length). In the forest, we chose dominant and co-dominant individuals only, as they are expected to account for the major part of stand water use; within the dominant and co-dominant sociological classes, we evenly selected individuals of relatively larger, medium and smaller diameters (min. diameter at breast height: 10 cm).

After sensor installation, insulative materials and aluminum foil were added to minimize temperature gradients and reflect radiation. Durable plastic foil was added for protection from rain. The sensors were connected to AM16/32 multiplexers connected to a CR1000 data logger (both Campbell Scientific Inc., Logan, USA). The signals from the sensors were recorded every 30 sec and averaged and stored every 10 min. In each plot, *SFD* was measured for a minimum period of three weeks. For oil palm, the mV-data from the logger were converted to *SFD* (g cm 2 h 1) with the equation by Granier (1985), but with an adjusted set of equation parameters *a* and *b* that was specifically derived for TDP measurements on oil palm leaf petioles (Niu et al. 2015).

As for oil palm by Niu et al. (2015), the TDP method was tested against gravimetric measurements in the laboratory for rubber and forest trees. The gravimetric readings and the estimates using the original Granier equation were within the 95 % confidence interval of a linear regression with a slope of 1. Thus, the original equation parameters (Granier 1985) were used for the analysis of rubber and forest trees.

To upscale from sap-flux point-measurements to water use rates per plant (kg day-1) and ultimately to stand transpiration (mm day-1), water conductive areas (cm^2) had to be established for each of the studied individuals and stands. For oil palm leaf petioles at the location of sensor installation, we used a linear regression between leaf baseline length and leaf conductive area, which was derived by Niu et al. (2015) for oil palms in the same study region based on laboratory staining experiments. To derive water conductive areas for dicot trees in forest and rubber plots, we measured the radial patterns of *SFD* with increasing depth (*d*, cm) into the xylem (0-8 cm, 1 cm resolution) with heat field deformation sensors (HFD, Nadezhdina, 2012, sensors from ICT International, Armidale, Australia) in 10 individuals per land use type. The measurements were conducted in parallel to TDP measurements (0-2.5 cm depth) on these individuals; HFD sensors were installed in between TDP sensors (North and South), i.e. in the West, at a similar height on the tree. The radial *SFD* patterns obtained by the HFD measurements were normalized to a depth of 1.25 cm (center of TDP sensors) to allow for an extrapolation of the single-point TDP measurements in the outer xylem (0-2.5 cm) to whole-tree water use rates (following Oishi et al. 2008). To subsequently upscale to stand-scale transpiration rates inventory data were used.

The sap flux measurements were conducted between March 2013 and April 2014. As most measurements could not be conducted in parallel for logistical reasons, we used the respective averages of the three most sunny and dry days within each measurement period (min. 3 weeks) for the analysis of the spatial variability in transpiration rates between plots, as to minimize dayto-day variability induced by weather.

Soil characteristics and erosion

Soil samples were collected per horizon in one soil pit on each plot. The subsoil under plantations was not affected by enhanced decomposition processes after forest conversion (Guillaume et al. 2015). Carbon content and C/N ratio below the Ah horizons were similar under forest and plantations. Therefore, we assessed $\delta^{13}C$ values) in the plantation subsoil was similar to the values in the forest subsoil prior to conversion. Consequently, when an identical subsoil dept $\delta^{13}C$ in the plantation than the forest, we suggest that this layer experienced a vertical shift towards the soil surface after erosional loss of the upper layer.

A power function describing the increase in $\delta^{13}C$ with depth under forest was fitted in Statistica 10 using Equation A1.1.

$$\delta^{13}C_{d} = \delta^{13}C_{Ah} d^{-l} \quad (A.1.1)$$

where C(d), $\delta^{13}C(d)$, C(Ah) and $\delta^{13}C$ (Ah)are the C content and the $\delta^{13}C$ value estimated for the depth *d* and measured in the Ah horizon, respectively, *d* the depth in cm and l the fitted parameters of the function. Regressions were fitted using all samples below the Ah horizons in the four forest replicate plots.

Erosion was calculated using the power function describing the distribution of $\delta^{13}C$ with soil depth in the forest plots $\delta^{13}C$ in the plantation subsoil resulted from shift in the depth due to the erosion after conversion, we calculated the original depth before erosion for all samples under plantations by modifying Equation A1.2:

$$d_b = 10^{\frac{log_{10}(\delta 13C_d/\delta 13C_{Ah})}{-l}} \quad (A1.2)$$

where d_b is the estimated depth before the conversion to plantation, $\delta^{13}C_d$ is the $\delta^{13}C$ values of the samples under plantation at depth *d*, 1 $\delta^{13}C_{Ah}$ is the mean $\delta^{13}C$ values of the Ah horizons under forest, and *l* is the parameters estimated for the soils under forest. The difference between the estimated depth before conversion (*db*) and depth at which the sample was collected (*d*) corresponds to erosion. The erosion for one plantation plot was calculated by averaging the erosion estimated for each sample collected in the plot. We excluded Ah horizons and samples deeper than 77 cm, which corresponds to the deepest sample under forest.

Microclimatic effects of land use change

A 2.5 m aluminum mast was placed in the center of the plots. A thermo-hygrometer (Galltec Mella, Bondorf, Germany) was installed at 2 m height in the mast and a soil temperature and moisture sensor (Trime-Pico 32, IMKO, Ettlingen, Germany) was placed 0.3 m under the soil surface. Both sensors were connected to a data logger (LogTrans16-GPRS, UIT, Dresden, Germany). Data were recorded every hour, for 16 months from June 2013 on.

Micro-catchment related measurements

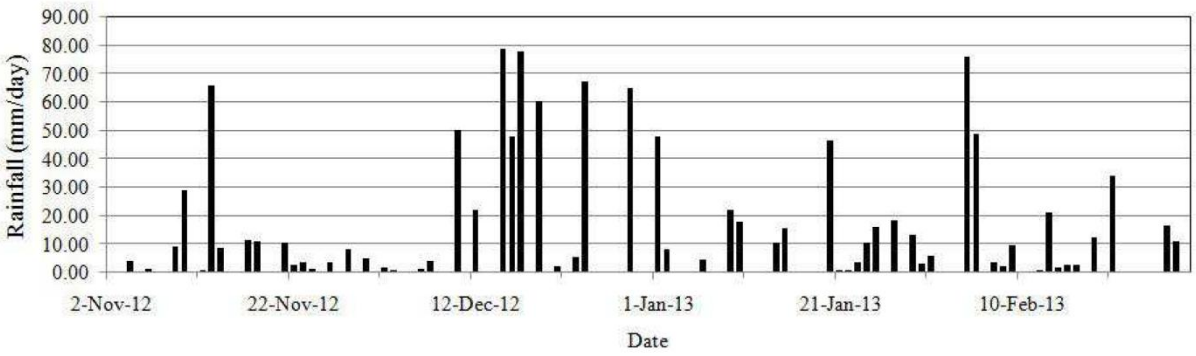
General catchment characteristics

Within two small catchments partly encompassing the oil palm and rubber plantations (plots HO1-4, HR1-4, Fig. 1), we recorded streamflow and measured rainfall interception for four months. One catchment (extension of 14.2 ha) was dominated by 10-14 year-old oil palm plantations (90 % of the area). The other catchment (4.9 ha) consisted of different rubber stands: eight year-old (19 % of the area) and 30 year-old (56 % of the area) mono-culture rubber plantations and jungle rubber (25 % of the area), a mix of rubber trees and naturally established dicot tree species. We selected a two week period (7 to 20 Nov 2013) of the recorded hydrographs encompassing both dry and rainy conditions. Rainfall interception of the oil palm and rubber monocultures in the respective catchments was assessed by measuring throughfall and stemflow, and subtracting them from incident rainfall.

Precipitation

We measured incident rainfall with three ombrometers (154 cm^2 collection area each) in open areas no more than 100 m from the respective catchments. Data were recorded manually at 6 am every day. We observed 30 rainfall events during our measurement period from November 2012 to February 2013, ranging from light to heavy rain (see Fig. A1.1).

Table 1: Quantities of daily rainfall in the study area from November 2012 to February 2013.



Streamflow

The two catchments were instrumented with a rectangular weir. The water levels in the weirs were continuously recorded using a HOBO Water Level Data Logger (Type U20-001-01, Onset, Bourne, MA, USA). Recorded water levels were converted to discharge units using Equation A1.3.

$$Q_r = 0.57\ H^{1.44} \quad (A1.3)$$

Where Q_r is rectangular weir discharge (l s^{-1}) and H is the water level in the weir (cm).

Throughfall

Throughfall samplers were made of 10-liter-canisters with funnels attached to the top for water collection. In oil palm plantations, the samplers were installed in diagonal patterns between adjacent palms. In total, the measurements were carried out in eight diagonal lines, where four lines represent 2 m and 4 m distance from respective trunks and the remaining four lines represent 1 m and 3 m distance from the trunk. Combined, the throughfall data thus had a resolution of 1 m. In rubber plantations, throughfall samplers were placed between adjacent rubber trees at distances of 1 m and 2 m from the trunk. Recordings were taken daily between November 2012 and February 2013.

Stemflow

Stemflow was measured by circling and sticking semicircle-shaped metal sheets from the top to the bottom of the trunk. The circling ended 50 cm above ground to allow for the placement of water collectors beneath it. Stemflow collectors were installed on four oil palm and six rubber trunks, respectively. The measurements were conducted between November 2012 and February 2013.

Interception

Interception was calculated by subtracting stemflow and throughfall from incident rainfall at the plot scale. Given that interception is based on the area of palm or tree canopy cover, stemflow data were normalized with canopy area before subtraction. Throughfall values on the canopy level were obtained by averaging measurements at various distances from the trunks of several individuals.

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3. Appendix to chapter III: Flooding and land use change in Jambi Province, Sumatra

Appendix 1: Biodiversity enrichment experiment

Table A1.1: Information regarding the plots of the biodiversity enrichment experiment (EFForTS-BEE) where water infiltration has been measured. Details on the species composition, plot size and tree diversity are described in Teuscher et al. (2016). A: *Parkia speciosa* (Fabaceae); B: *Archidendron pauciflorum* (Fabaceae); C: *Durio zibethinus* (Malvaceae); D: *Dyera polyphylla* (Apocynaceae); E: *Peronema canescens* (Lamiaceae); F: *Shorea leprosula* (Dipterocarpaceae)

Plot ID	Lat	Long	Plot size	Diversity Level	Composition of the planted tree species	Number of planted trees
1	-1.94162	103.2519	40	1	A	400
2	-1.94174	103.253	20	3	ACF	99
3	-1.9433	103.2518	20	2	CD	100
4	-1.94321	103.2532	10	1	F	25
5	-1.94478	103.2518	40	1	B	400
6	-1.94462	103.2532	5	1	E	6
7	-1.94469	103.2552	40	3	AEF	399
8	-1.94587	103.2491	5	1	F	6
12	-1.94589	103.2543	20	1	C	100
13	-1.94591	103.2559	10	1	E	25
17	-1.94734	103.2531	20	1	F	100
22	-1.94873	103.2491	5	2	BF	6
24	-1.94838	103.2543	40	2	CE	400
26	-1.94849	103.2572	40	2	DF	400
27	-1.94992	103.2464	10	2	AE	24
28	-1.95002	103.2478	5	1	B	6
29	-1.94996	103.249	40	3	BCD	399
30	-1.94981	103.253	20	1	E	100
31	-1.94997	103.2545	5	1	C	6

34	-1.95143	103.2451	10	2	BD	24
35	-1.95182	103.2466	40	0	Z	0
36	-1.95106	103.2477	20	2	AF	100
37	-1.95118	103.2488	10	0	Z	0
38	-1.95172	103.2504	20	1	D	100
39	-1.95138	103.2518	5	2	AC	6
41	-1.95267	103.2438	10	1	A	25
42	-1.95276	103.245	5	1	D	6
44	-1.95271	103.2478	5	3	BEF	6
45	-1.95307	103.2487	40	1	E	400
46	-1.95442	103.2424	40	2	AB	400
47	-1.95395	103.2437	20	2	BE	100
48	-1.9541	103.2452	10	3	CEF	24
49	-1.954	103.2466	40	1	F	400
50	-1.95406	103.2478	5	6	ABCDEF	6
51	-1.95425	103.2491	20	1	A	100
53	-1.94325	103.2547	10	control		0
54	-1.9512	103.2558	10	control		0
55	-1.9513	103.2534	10	control		0
56	-1.95505	103.2461	10	control		0

Appendix 2: River discharge

Table A3.1: Mean water level (± standard deviation) at Pauh hydrological station and results of Mann-Kendall test (Mann-Kendall τ and p-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
Average (1997-2016)	7.07 (±2.05)	6.90 (±2.24)	6.80 (±2.46)	7.25 (±2.17)	6.47 (±1.94)	4.92 (±1.50)	4.74 (±1.58)	4.48 (±1.29)	4.43 (±1.32)	5.08 (±1.43)	7.05 (±1.73)	8.13 (±2.67)	6.88 (±1.47)	4.98 (±1.22)	6.07 (±1.29)
Mann-Kendall τ	0.13 (p<0.001)	0.23 (p<0.001)	0.22 (p<0.001)	0.33 (p<0.001)	0.28 (p<0.001)	0.25 (p<0.001)	0.21 (p<0.001)	0.05 (p =0.07)	0.05 (p =0.07)	-0.14 (p<0.001)	0.26 (p<0.001)	0.25 (p<0.001)	0.29 (p<0.001)	0.14 (p<0.05)	0.18 (p<0.001)

Table A3.2: Sum of days with water level >11 m at Pauh hydrological station and results of Mann-Kendall test (Mann-Kendall τ and p-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
Average (1997-2016)	1.8 (±1.6)	2.5 (±3.1)	2 (±2.7)	2.2 (±2.4)	1.8 (±1.0)	0	0	0	0	0.1	1.4 (±0.7)	3.6 (±4.3)	15.4 (±1.0)	0	15.4 (±1.0)
Mann-Kendall τ	0.49 (p=0.01)	0.28 (p=0.15)	0.24 (p=0.21)	0.23 (p <0.24)	0.23 (p <0.23)	-	-	-	-	0.32 (p=0.12)	0.59 (p<0.01)	0.25 (p=0.17)	0.45 (p<0.01)	0.32 (p=0.12)	0.45 (p<0.01)

Table A3.3: Average water level rise (m) (± standard deviation), based on the difference between average water levels of two consecutive days at Pauh hydrological station and results of Mann-Kendall test (Mann-Kendall τ and p-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
Average (1997-2016)	0.43 (±0.15)	0.50 (±0.22)	0.46 (±0.16)	0.43 (±0.24)	0.51 (±0.32)	0.43 (±0.21)	0.37 (±0.14)	0.40 (±0.30)	0.41 (±0.30)	0.42 (±0.26)	0.47 (±0.16)	0.53 (±0.22)	0.46 (±0.10)	0.42 (±0.13)	0.45 (±0.10)
Mann-Kendall τ	0.22 (*p*=0.21)	0.56 (*p*<0.01)	0.35 (*p*=0.05)	0.22 (*p*=0.21)	0.29 (*p*=0.09)	0.14 (*p*=0.44)	0.12 (*p*=0.54)	0.06 (*p*=0.77)	0.15 (*p*=0.40)	-0.03 (*p*=0.88)	0.18 (*p*=0.34)	0.12 (*p*=0.54)	0.16 (*p*<0.01)	0.14 (*p*<0.01)	0.16 (*p*<0.01)

Appendix 3: Determination of flood-risk areas

In order to map areas that are prone to flooding, we followed the guidelines of the Indonesian National Agency for Disaster Management (Badan Nasional Penanggulangan Bencana / BNPB), which requires two main input datasets, namely (1) a digital elevation model (DEM) and (2) the river flow network. We used the 3 arc-second (≈ 90 m) void-filled, open-access DEM "Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales" (HydroSHEDS) developed by the Conservation Science Program of the World Wildlife Fund For Nature (Lehner et al. 2008). This DEM presents a combination of the Shuttle Radar Topography Mission (SRTM-3) and the void-filled digital terrain elevation data (DTED®-1) (Lehner 2013). The river network is based on the corresponding vector layer from the Indonesian Geospatial Information Agency (Badan Informasi Geospasial / BIG 2017) digitally available for Jambi Province at the scales of 1:250,000 and 1:50,000. Building on these two datasets, we determined a flooding probability by combining the slope gradient, distance from the rivers and the modified topographic index (TI_m) :

$$TI_m = ln\left[\frac{a_d^n}{\tan(\beta)}\right]$$

where a_d is the local upslope contributing area per unit contour length; tan(β) is the local slope gradient; n is an exponent ($0.016x^{0.46}$) and x is the spatial resolution of the DEM (Manfreda et al. 2011; Manfreda et al. 2014). The TI_m was developed to delineate the exposure to flooding events on the basis of the basin topography (Manfreda et al. 2011). Eventually, an area was defined as flood-prone when (1) the distance to the river was < 300 m, (2) the slope gradient < 15% and (3) TI_m exceeded a threshold τ, which was set to $\tau = 10.89n + 2.282$ (based on BNPB 2016), and constitutes an area that equals or exceeds 0.2 % annual chance to be flooded (Holmes Jr. and Dinicola, 2010).

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Appendix 4: Precipitation

Table A4.1: Accumulated precipitation (mm) at Pauh meteorological station and results of Mann-Kendall test (Mann-Kendall τ and *p*-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
Average (2007-2016)	290.3 (±115.9)	216.7 (±74.1)	268.5 (±149.3)	280.3 (±94.6)	244.1 (±83.9)	109.6 (±53.0)	170.6 (±94.0)	126.6 (±85.2)	141.2 (±112.1)	256.1 (±110.3)	352.7 (±119.4)	365.0 A) (±162.8)	1993.1 (±392.7)	792.1 (±220.2)	2785.2 (±547.0)
Mann-Kendall τ	0.16 (*p*=0.59)	0.38 (*p*=0.15)	0.33 (*p*=0.21)	0.20 (*p*=0.47)	0.60 (*p* <0.05)	-0.04 (P =0.93)	-0.07 (*p* =0.86)	-0.20 (*p* =0.47)	-0.24 (*p* =0.37)	-0.33 (*p* =0.21)	0.56 (*p* <0.05)	0.06 (*p* =0.92)	0.02 (*p* =0.13)	-0.02 (*p* =0.33)	0.03 (*p* =0.65)

[A)] No data for December 2012 available

Table A4.2: Average precipitation intensity index (± standard deviation) at Pauh meteorological station and results of Mann-Kendall test (Mann-Kendall τ and *p*-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
2007-2016	15.9 (±13.3)	17.6 (±13.5)	17.2 (±16.1)	22.0 (±19.0)	21.6 (±21.2)	13.7 (±13.5)	18.5 (±22.5)	15.4 (±16.5)	17.3 (±16.9)	17.1 (±14.0)	24.4 (±22.4)	23.3 (±23.1)	20.2 (±18.8)	16.0 (±17.6)	19.0 (±18.6)
Mann-Kendall τ	-0.14 (P =0.13)	0.11 (P =0.26)	0.16 (P =0.04)	-0.09 (P =0.29)	0.07 (P =0.40)	-0.08 (P =0.40)	0.14 (P =0.10)	-0.09 (P =0.32)	-0.05 (P =0.66)	-0.14 (P =0.13)	0.02 (P =0.81)	0.06 (P =0.47)	0.02 (P =0.59)	-0.02 (P =0.71)	0.01 (P =0.81)

Table A4.3: Mean precipitation (mm) at Jambi airport meteorological station and results of Mann-Kendall test (Mann-Kendall τ and *p*-value) during the period 1978-2016.

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
1978-2016	199.3 (±85.7)	180.2 (±79.9)	233.9 (±82.7)	256.0 (±90.0)	170.5 (±64.8)	112.4 (±64.6)	112.5 (±81.4)	124.6 (±92.9)	129.6 (±86.1)	223.0 (±105.8)	241.1 (±98.9)	248.2 (±86.6)	1798.2 (±91.6)	491.7 (±81.4)	2289.9 (±99.9)
Mann-Kendall τ	-0.28 (P =0.01)	-0.08 (P =0.51)	-0.02 (P =0.85)	-0.22 (P =0.05)	-0.12 (P =0.31)	-0.08 (P =0.51)	0.16 (P =0.16)	0.10 (P =0.38)	-0.16 (P =0.16)	-0.13 (P =0.24)	-0.06 (P =0.63)	0.02 (P =0.85)	0.09 (P =0.02)	0.03 (P =0.54)	-0.05 (P =0.10)

Table A4.4: Average precipitation intensity index (± standard deviation) at Jambi Airport meteorological station and results of Mann-Kendall test (Mann-Kendall τ and *p*-value).

Year	Month												Wet season (Oct.-May)	Dry season (Jun.-Sept.)	Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.			
1991-2016	11.3 (±11.9)	13.1 (±13.4)	16.1 (±16.6)	14.2 (±14.2)	12.8 (±12.8)	11.9 (±14.6)	15.3 (±18.2)	13.7 (±15.5)	11.1 (±12.0)	14.7 (±12.4)	14.4 (±13.0)	15.7 (±15.0)	14.0 (±13.8)	13.0 (±15.2)	13.8 (±14.2)
Mann-Kendall τ	-0.01 (P =0.79)	0.05 (P =0.34)	-0.13 (P <0.01)	0.02 (P =0.74)	-0.03 (P =0.54)	-0.08 (P =0.18)	-0.04 (P =0.54)	0.01 (P =0.92)	-0.05 (P =0.44)	-0.03 (P =0.57)	-0.05 (P =0.36)	-0.03 (P =0.56)	0.05 (P =0.01)	0.0 (P =0.96)	-0.03 (P =0.06)

Appendix 5: Accuracy statistics of land use/cover classes

Table A5.1: Accuracy statistics and area proportion of each land use/cover class in the Tembesi watershed for the year 2013 (recalculated from Melati 2017).

Land use/ cover class	Accuracy			Area proportion (%)	
	User's	Producer's	Overall	Map	Estimated
Agriculture	72.4 ± 16.6	95.6 ± 5.4	85.8 ± 4.4	16.3	12.4 ± 2.8
Bush/bareland	79.4 ± 10.1	60.3 ± 17.4		7.1	9.4 ± 2.8
Forest	93.9 ± 6.8	95.4 ± 3.2		38.1	37.5 ± 2.9
Oil palm	83.3 ± 10	68.5 ± 13.8		10.8	13.1 ± 2.8
Rubber	86.4 ± 7.5	90.9 ± 6.7		25.6	24.4 ± 2.6
Settlement	81.3 ± 19.8	35.2 ± 22.3		1.3	2.9 ± 1.8
Water body	50 ± 43.8	100 ± 0		0.8	0.4 ± 0.3