Governing land use and restoration:

The long-term progress of environmental and agricultural policies on sustainable rangeland management and restoration in Iceland

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*A 150 ECTS Academic Dissertation Presented in Candidacy for
the Degree of Doctor of Philosophy in Environmental Sciences*

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June 2020

"The best way to deduce the system´s purpose is to watch for a while
to see how the system behaves" (Meadows, 2008)

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Clarification of contribution

I hereby declare that the ideas behind this research, the writing of the following thesis and the four accompanying papers is my work, done under the supervision and with assistance of my supervisors, Professor Ása L. Aradóttir, Professor Susan Baker and Professor Guðmundur Halldórsson.

The contribution of Þórunn Pétursdóttir to the papers included in this thesis was as follows:

Paper I: All co-authors participated in structuring the content of the paper, based on a comprehensive review of ecological restoration in Iceland, published in Icelandic in 2011. Professor Aradóttir drafted the manuscript and coordinated the writings with the assistance of Petursdottir. All co-authors contributed to the writings but Professor Aradóttir was responsible for correspondence with the scientific journal.

Paper II: Petursdottir planned the work and collected all data presented in the paper, except the interviews with the farmers, which were conducted in collaboration with Dr. Montanarella. Petursdottir analyzed and interpreted the data and wrote the manuscript that was revised and approved by all co-authors. Petursdottir corresponded with the scientific journal.

Paper III: Petursdottir collected all the data presented in the paper. The data was collected via a survey that was distributed to identified stakeholders, nationwide. Petursdottir analyzed and interpreted the data and wrote the manuscript that was revised and approved by all co-authors. Petursdottir corresponded with the scientific journal.

Paper IV: Petursdottir collected all the data presented in the paper. The data was collected via a survey that was distributed to identified stakeholders, nationwide and through secondary sources. Petursdottir analyzed and interpreted the data and wrote the manuscript that was revised and approved by all co-authors. Petursdottir corresponded with the scientific journal.

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Þórunn Pétursdóttir

Abstract

Every summer, free-roaming sheep graze large parts of Icelandic rangeland ecosystems, even though some of these rangeland areas are estimated to be in a severely eroded or even collapsed ecological condition. Improved rangeland management and ecosystem restoration of severely degraded rangelands have been designated as official agricultural and environmental policy tasks of the Icelandic government for the last decades. Several new agri-environmental programs and projects have been established since 1990, with the aim of maintaining and improving the ecological condition of rangeland ecosystem and to facilitate behavioral changes among sheep farmers in relation to sustainable rangeland management. Nevertheless, little is known about the overall long-term progress of these activities and their processes and outcomes have never been studied in an interdisciplinary manner.

The main aim of this thesis was to carry out research on rangeland management and restoration in Iceland by examining, through a social-ecological lens, if the expected long-term progress of identified policy goals and all related programs and projects has been achieved. The first step of the research was to do a historical analysis on the main drivers of ecological restoration in Iceland during the last century and map if the drivers had changed over time. That study was based on a catalogue of 100 restoration programs, projects and areas of restoration activity (75-85% of all restoration activities in Iceland). The second step included an investigation of the SES surrounding rangeland restoration in Iceland to assess whether social factors, such as stakeholders´ attitude and behavior, influenced the effectiveness of agricultural and environmental policies related to rangeland restoration and improved rangeland management. That study was based on qualitative research, where 15 stakeholders were interviewed. The third step was to examine if a large-scale rangeland restoration program had facilitated expected attitudinal and behavioral changes among the sheep farmers who participated in the program. This step was based on a questionnaire where sheep farmers were asked about their attitude and behavior in relation to rangeland restoration and land management and the replies from participating farmers were compared to the replies from a control group of non-participating farmers. The fourth step was to map the administrative structure that steers rangeland management and explore the governance system's structure and functions in order to elucidate the policy context in which agricultural and environmental policy targets for improved rangeland management practices were framed. This final study was also based on a questionnaire that was distributed to selected public and semi- public sector employees and sheep farmers. The results were used to gauge the participants' attitude concerning rangeland management, their perception on state support and level of collaboration related to rangeland restoration and their views on current policies related to rangeland management.

The findings from the first step of the research revealed that catastrophic soil erosion, depleting farmlands in the beginning of last century, was an early driver of ecosystem restoration in Iceland. The

findings also showed that soil erosion still ranked high as a driver in the early 2000s, although other drivers, such as moral values and nature conservation, along with concerns about use values, such as in relation to recreation, were also strong motivators for restoration actions. Public policy programmes were found to be a minor driver, which might indicate weaknesses in the policy instruments used for ecological restoration. The findings from the second step of the research showed that social factors, such as attitude and behavior, can be used as indicators of the effectiveness of restoration policies. They also pointed to a lack of functionality in the governance of SESs that could deter progress in achieving policy goals, and possibly block the necessary behavioral change among related stakeholders. Results from the third step showed that the restoration program investigated had not facilitated behavioral change in relation to improved rangeland management among participating farmers compared with non-participants, even though the participating farmers were shown to be more aware of the potential of rangeland restoration and were more motivated to engage in further collaboration, compared to the non-participants. The results also indicated that the direct incentives provided by the program were pushing the participants to favor agronomic instead of ecological approaches in their restoration activities. Furthermore, several organizational errors within the program management were detected, for instance regarding integration of participatory approaches and level of personal connections between the participants and the Soil Conservation Service that might be halting its further progress. Results from the fourth step indicated strongly that neither the governance process nor the current administrative structure of rangeland management had significantly facilitated expected changes in attitude among local authorities or among sheep farmers needed to bring about improved rangeland management practices within the agricultural sector.

The key findings of this thesis were that the stated policy objectives of improving the ecological condition of rangeland, including the objectives of current agri-environmental programs and project related to rangeland management, have not yet been fully achieved. The thesis also pointed to the need for improved governance practices, by highlighting that the governance system for rangeland management was structurally limited, suffering from weak vertical and horizontal integration, and not designed to maintain and improve the ecological condition of rangelands' ecosystems in the context of traditional sheep grazing management practices.

Ágrip

Stór hluti íslenskra úthagavistkerfa er vistfræðilega í hnignuðu eða alvarlega röskuðu ástandi. Hluti þessara svæða er engu að síður nýttur til sauðfjárbeitar. Undanfarna áratugi hafa íslensk stjórnvöld lagt áherslu á bætta landnýtingu og endurheimt úthagavistkerfa og sett fram nýjar landbúnaðar- og umhverfisstefnur til þess að vinna að þeim markmiðum. Frá árinu 1990 hafa stjórnvöld innleitt nýjar stefnur, áætlanir og verkefni sem miða að því að viðhalda og bæta vistfræðilegt ástand úthaga og stuðla að því að landnýting á vegum sauðfjárbænda verði sjálfbær. Lítið er vitað um langtíma árangur þessara stefna og tengdra verkefna og ferlar þeirra og útkomur hafa aldrei verið skoðaðar samþætt eða þverfaglega.

Meginmarkmið þessarar ritgerðar var að rannsaka stjórnun á nýtingu og endurheimt úthagavistkerfa í gegnum samfélags- og vistfræðilega greiningu, til að meta hvort langtímaárangur valinna stefnumiða stjórnvalda, og verkefna tengdum þeim, hafi náðst. Fyrsti hluti rannsóknarinnar fól í sér að gera sögulega greiningu á helstu hvötum að endurheimt vistkerfa á Íslandi síðustu 100 árin og kortleggja hvort hvatarnir hefðu breyst í gegnum árin. Rannsóknin byggði á yfirliti yfir 100 endurheimtarverkefni og svæði þar sem unnið hafi verið að endurheimt (75-85% af öllum endurheimtaraðgerðum á Íslandi). Í öðrum hluta hennar var samfélags- og vistfræðilega kerfið tengt endurheimt úthagavistkerfa á Íslandi skoðað til að meta hvort félagslegir þættir eins og viðhorf og hegðun hagaðila hefðu áhrif á innleiðingu og virkni landbúnaðar- og umhverfisstefna tengdum stjórnun á nýtingu og endurheimt úthagavistkerfa. Rannsóknin byggði á eigindlegri rannsókn (viðtölum) þar sem rætt var við 15 hagaðila. Þriðji hlutinn fól í sér að meta hvort samstarfsverkefni Landgræðslunnar og bænda um endurheimt úthagavistkerfa (Bændur græða landið) hefði stuðlað að viðhorfs- og hegðunarbreytingum á meðal sauðfjárbændanna sem tóku þátt í verkefninu. Sú rannsókn byggði á spurningakönnun þar sem allir sauðfjárbændur voru spurðir um viðhorf sín og hegðun í tengslum við endurheimt úthagavistkerfa og landnýtingu. Svör bændanna sem tóku þátt í endurheimtarverkefninu voru síðan borin saman við svör þeirra bænda sem ekki tóku þátt. Fjórða hlutinn snérist um að kortleggja stjórnsýsluna utan um nýtingu úthagavistkerfa og skoða samsetningu og virkni stjórnkerfisins til að skilja betur tengingarnar á milli núverandi landbúnaðar- og umhverfistengdra stefnumiða og það umhverfi sem markar stefnurnar. Þessi síðasti hluti rannsóknarinnar byggði einnig á niðurstöðum spurningakönnunar sem var dreift til valinna aðila sem störfuðu innan stjórnsýslunnar, tengdra samtaka og til sauðfjárbænda. Niðurstöðurnar voru nýttar til að meta viðhorf þátttakanda til stjórnunar á nýtingu úthagavistkerfa, skoðanir á stuðningi ríkisins til þessa málaflokks, vægi samstarfs um endurheimt úthagavistkerfa og sýn þeirra á núverandi stefnumið tengd nýtingu úthagavistkerfa.

Niðurstöður fyrsta hluta rannsóknarinnar sýndu að gríðarleg jarðvegseyðing sem eyddi bújörðum í upphafi síðustu aldar, var upphafshvati endurheimtar vistkerfa á Íslandi. Í upphafi 21. aldarinnar var vægi jarðvegseyðingar enn hátt þó aðrir hvatar, svo sem siðferðileg gildi, náttúruvernd og útivistargildi

svæða væru einnig sterkir hvatar að baki endurheimtarverkefnum. Opinberar stefnumótunaráætlanir reyndust ekki öflugir hvatar, sem gaf til kynna undirliggjandi veikleika í opinberum stjórntækjum sem ætlað er að hafa áhrif á bætta landnýtingu og aukna endurheimt raskaðra vistkerfa. Niðurstöður annars hluta rannsóknarinnar bentu til að hægt sé að nýta samfélagslega þætti eins og viðhorf og hegðun fólks til að meta virkni stefnutengdra markmiða hvað varðar endurheimt vistkerfa. Niðurstöðurnar bentu einnig til takmarkana á virkni stjórnkerfis innan samsetts samfélags- og vistfræðilegs kerfis sem geta dregið úr möguleikum á að ná stefnutengdum markmiðum og hugsanlega einnig hindrað nauðsynlegar breytingar sem þurfa að verða á hegðun fólks til að markmiðin náist. Niðurstöður þriðja hluta rannsóknarinnar sýndu að endurheimtarverkefnið (Bændur græða landið, BGL) sem var til skoðunar hafði ekki ýtt marktækt undir hegðunarbreytingar hvað varðaði skipulag landnýtingar á meðal þeirra bænda sem tóku þátt í verkefninu samanborið við þá sem tóku ekki þátt í því. Bændurnir sem voru þátttakendur í verkefninu voru engu að síður betur meðvitaðir um hvaða svæði var mögulegt að endurheimta og voru tilbúnari í samstarf um slík verkefni en þeir bændur sem ekki tóku þátt. Rannsóknin leiddi einnig í ljós að beinu hvatarnir sem fylgdu þátttöku í verkefninu virtust ýta bændunum frekar í átt að nota ræktunarmiðaðar aðferðir í stað vistfræðilegra nálgana við endurheimt vistkerfa. Matið sem gert var í þriðja hluta rannsóknarinnar leiddi í ljós nokkrar skipulagsvillur (e. organizational errors) innan stjórnunar BGL verkefnisins sem gætu verið að aftra frekari árangri þess. Villurnar tengdust til að mynda innleiðingu þátttökunálgana í verkefnið sem og styrk persónulegra tengsla milli þátttakenda í verkefninu og starfsmanna Landgræðslunnar annars vegar og hins vegar traust þátttakenda til Landgræðslunnar sem stofnunar. Niðurstöður fjórða hluti rannsóknarinnar gáfu sterklega til kynna að hvorki núverandi stjórnsýslukerfi sem heldur utan um nýtingu úthagavistkerfa, né stjórnarhættir innan þess, hafi marktækt ýtt undir væntar viðhorfsbreytingar á meðal sveitarstjórnarfólks eða sauðfjárbænda, eitthvað sem nauðsynlega þarf að gerast svo að núverandi nýtingarform úthagavistkerfa innan landbúnaðargeirans batni til frambúðar.

Meginniðurstöður þessarar ritgerðar voru að skilgreind stefnumið stjórnvalda sem lúta að því að bæta vistfræðilegt ástand úthaga sem og markmið núverandi landbúnaðar- og umhverfistengdra áætlana og verkefna sem tengjast stjórnun á nýtingu úthagavistkerfa hafa ekki náðst að fullu. Ritgerðin sýndi einnig fram á nauðsyn bættra stjórnunarhátta með því að draga fram að stjórnkerfið sem tengist úthaganýtingu var ekki nógu vel uppbyggt og það hamlaði öllu flæði tengdu því. Hvorki láréttar né lóðréttar tengingar kerfisins voru nægjanlega samþættar eða fyllilega virkar og stjórnkerfið því ekki í stakk búið til að viðhalda og efla vistfræðilegt ástand úthagavistkerfa miðað við núverandi beitarstjórnunarkerfi.

Lykilorð: Stjórnun á nýtingu náttúruauðlinda, endurheimt vistkerfa, samfélags- og vistfræðileg kerfi, úthagavistkerfi, árangursmat

Acknowledgements

The making of this thesis has been quite a long journey, with lots of successes but also failures involved. Even though some parts of the path were tougher and steeper than others and there were periods when the thesis felt like a heavy stone around my neck, deep down I always believed that one day this journey would come to an end and finally it came true.

First of all, I sincerely thank Ása L. Aradóttir, my main supervisor, for following me all the way through, never losing faith in me and always being there, ready to assist whenever needed. I also thank Susan Baker, one of my two co-supervisors for her highly valuable inputs and support. She came to Iceland several years ago to give a talk at a conference; I listened to her presentation and thought wow, I really would like to get her to my PhD committee. And Susan agreed to jump on board without knowing me at all. For that, I will always be endlessly grateful. She and Ása were the ideal team of scientists for an optimistic person (like me) that decided to do a multilayered research without knowing much about the complexity of the work she was about to implement. Last, but not least I want to express gratitude to my other co-supervisor, Guðmundur Halldórsson. He has been of great help and his valuable comments, kindness and calm presence in every situation were always highly appreciated.

I thank Sveinn Runólfsson, the former director of the SCSI for his valuable support and for giving me the opportunity to go abroad to study. I also thank the IES at the JRC of the European Commission for offering me a three years PhD research position. That was a game changer and during my years in Italy I met lot of great people and made a lifelong friendship with many of them. The thesis was also supported by the Energy Research Fund of Landsvirkjun and the Agricultural Productivity Fund in Iceland and I kindly thank for that.

I thank Arna Björk, Þorsteinn, Andrés and Edda Linn my current and former colleagues at the SCSI for their contribution to my work, I don´t know what I would have done without all these lovely people around. That goes indeed for all my colleagues at the SCSI, thanks for being there! Also, to my colleagues at the Agricultural University; thanks for believing in me, Magga, Óli, Jón and the others. Furthermore, I thank Árni Bragason, the current director of the SCSI for his support and for believing that I would indeed manage to finish this parallel to my work.

Thanks to my family, in particular, to my children and grandchildren, my true wealth in this world. Thanks for unconditionally loving your crazy mum :). Finally, to Mummi, my husband – because of your endless love and supportive care, I managed to get through the last obstacles in the way and wrap this thesis up. Love you big time! "La vita e bella"

Content

List of Original Papers

The present thesis is based on the following publications, which will be referred to by their Roman numerals.

I. Aradóttir, Á. L., T. Petursdottir, G. Halldorsson, K. Svavarsdottir, and O. Arnalds. 2013. Drivers of ecological restoration: lessons from a century of restoration in Iceland. *Ecology and Society* 18(4): 33. http://dx.doi.org/10.5751/ES-05946-180433

II. Petursdottir, T., O. Arnalds, S. Baker, L. Montanarella, and Á. Aradóttir. 2013. A social–ecological system approach to analyze stakeholders' interactions within a large-scale rangeland restoration program. *Ecology and Society* 18(2): 29. http://dx.doi.org/10.5751/ES-05399-180229

III. Petursdottir, T., Aradottir, A. L., Baker, S., Halldorsson, G., & Sonneveld, B. (2017). Successes and Failures in Rangeland Restoration: An Icelandic Case Study. *Land Degradation & Development*, *28*(1), 34-45. https://doi.org/10.1002/ldr.2579

IV. Petursdottir, T., Baker, S., & Aradottir, A. L. (2020). Functional silos and other governance challenges of rangeland management in Iceland. *Environmental Science & Policy*, *105*, 37-46. https://doi.org/10.1016/j.envsci.2019.12.006

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Introduction

"*Rangelands are those lands on which the native vegetation (climax or natural potential plant community) is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing use. Rangelands include natural grassland, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities*" (EPA, 2018).

Nearly 80% of Iceland´s terrestrial ecosystems can be classified as rangelands (Arnalds, *et al.*, 2001). Many of these rangelands are highland commons. Although these commons are officially owned by the State, they are geographically located within many of Iceland´s municipalities and their tenure (for example, regarding planning) lies with the respective local authorities of the adjacent municipalities. Nevertheless, the traditional rights or ownership of the grazing access belongs to the local farmers or other local landowners (Ogmundardottir, 2011). Other rangelands than the highland commons are usually in private ownership, often commonly owned by two or more landowners and their utilization thus is managed collectively. Each summer, large parts of the Icelandic rangelands are grazed by free roaming domestic sheep (Arnalds & Barkarson, 2003).

Sheep farming is the most widely distributed agricultural sector in Iceland in terms of geographical location and number of farms. Nevertheless, its share of the annual revenues derived from the agricultural sector in total is only around 17% (Karlsson, 2019). As the annual revenues of sheep farms are low on average (Karlsson *et al.*, 2015), the summer grazing of rangelands is seen as an important socio-economic factor by the sheep farming community (Arnalds & Barkarson, 2003). The grazing access is free of charge and the collaborative annual sheep gathering from the highland rangelands and the following pens, where each farmstead collects its livestock back from the larger flock of sheep, is a cultural heritage that has been practiced for centuries and is still a highly valued social activity within rural communities (Ogmundardottir, 2011).

Even though sheep farmers consider rangeland grazing to be of high socio-economic importance for their farming, over 50% of the Icelandic rangeland ecosystems are currently estimated to be ecologically degraded (Arnalds & Barkarson, 2003). Some of the areas are severely degraded or even eroded, thus estimated unfit for grazing (Arnalds *et al.*, 2001). Nevertheless, many of the degraded rangelands are still grazed every summer by free roaming sheep (Arnalds, 2019). Although rangeland restoration has been a policy goal of the Icelandic government for over a century, ecosystem degradation is still one of Iceland´s key environmental challenges (Aradottir *et al.*, 2013).

All actions related to rangeland management and ecosystem restoration of degraded rangelands in Iceland are embedded in a complex human-nature system, here after referred to as a social-ecological system (SES). Prevailing governance, such as policies, laws and regulations, agri-environmental education, agri-environmental advisory systems, direct and indirect incentives and subsidy payments

are supposed to direct land use towards sustainability, parallel to continued summer grazing of rangelands. But it is not clear how effectively the governance system of the social-ecological system of rangeland management is supporting that objective as the governance practices have never been comprehensively evaluated.

In this thesis I will analyze the social-ecological system (SES) of rangeland management in Iceland from the perspective of natural science and explore in particular if the current structure and functions of the governance system of the SES are facilitating sustainable rangeland management, in line with current policy targets. To unpack such an SES, one must be capable of identifying the structure of the system´s ecological as well as its social subsystem, how each of the subsystems function individually, how they interact, and their outcomes (Ostrom, 2009). Preferably, an investigation of SES should be based on a framework that is designed for SES analysis and include a process and outcome evaluation to regularly estimate whether all expected policy objectives and tasks are met. As the focus here is to explore the structure and functions of the governance system, the concept of good governance practices must be included.

The importance of understanding ecosystems´ structure (for example, species composition and soil type) and functions (for example, biomass production and carbon sequestration) in natural resource management is well known from the natural scientist´s viewpoint. But the field of natural science generally does not fully address concepts of high importance in natural resource management, such as social-ecological systems, SES frameworks, good governance practices and policy evaluation. The following sub-sections of the introduction will focus on clarifying these concepts and highlight why they are essential in the context of an SES analyses, such as the one performed in this thesis. As social-ecological system´s processes are circular and interlinked, the next subsection will start from the very beginning and focus on the concepts of system and system thinking as the baseline for understanding SESs.

What is a system and system thinking?

A system is *"a set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its "function" or "purpose"* (Meadows, 2008 page 188). Every system is dynamic, with spatial and temporal boundaries and influenced by its environment. The elements of a system can be physical units, such as people or buildings, or intangibles like norms and traditions. The elements are linked together with interconnections that operate through physical flows and/or through a flow of information or informal signals affecting the system´s decision-making process (Meadows, 2008). Interconnections within a system are a delicate part of its pattern or structure - where any changes in the connections may greatly alter the system´s behavior. In most cases the functions of a system are a crucial determinant

of its behavior, as these components control the system´s overall progress and can profoundly change a system although its elements and interconnections remain the same. An essential behavior of successful systems is to keep their overall functions and sub-purposes in line with stated goals (Meadows, 2008).

A systems thinking approach is used to analyze patterns in systems by looking at them from a holistic viewpoint rather than fragmented entities or unrelated, individually managed units (Senge, 1990). Arnold & Wade (2015, p. 675) define systems thinking as *"a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system'*. Systems thinking is increasingly applied in natural resource management (e.g., Bosch *et al.*, 2007). This approach has been proven highly useful as it reveals the linkages interconnecting systems of various levels and provides feedback control supporting adaptive management of natural resource utilization (e.g., Berkes & Folke, 2000; Young, 2009).

Social-Ecological Systems (SES)
Successful management of natural resources necessitates the interlinking of all ecological and social components related to the resource use. Such compound systems are called social-ecological systems (SES) (Ostrom, 2007; Ostrom, 2009; Folke *et al.*, 2016). These are assemblages of multiple social and ecological components with the ecological system that are intricately linked with, and affected by, one or more social systems (Anderies *et al.*, 2004). SESs are understood as complex adaptive systems (e.g., Levin *et al.*, 2013) as each system is non-linear, cross-scale, multivariable and a dynamic unit, embedded in various other SESs of different origins (McGinnis & Ostrom, 2014; Epstein *et al.*, 2015). Such compound SESs interact interdependently, but they also contain interactive subsystems (McGinnis & Ostrom, 2014). The SES approach highlights that societies, communities, people, economies, and cultures are interlinked to the world´s ecosystems and constantly shaping them from local to global scales (Folke *et al.*, 2016). Furthermore, to manage such multilayered systems in a sustainable way, the SES approach underscores the importance of understanding the institutional setting that surround all SESs (Epstein *et al.*, 2015; Cash *et al.*, 2006). This setting includes the informal and formal norms, rules and conventions that are used by societies to structure interactions and increase predictability in situations where independent choices are prevailing (Ostrom, 2005).

Sustainable natural resource management, such as rangeland grazing management, centers on maintaining structurally diverse and well-functioning ecosystems (Yang & Konrad, 2010). Thus, it requires that actors and agents involved in the management process of the respective SES have an understanding of ecoliteracy and what the terms ecological processes and ecological capacity stand for (Briske, 2017). Preferably, they should also know the related institutions and how they work, and understand the process of stakeholder involvement, resource tenure systems and how to

achieve social consensus concerning environmental issues (Berkes & Folke, 2000; Liu *et al.*, 2007; McGinnis & Ostrom, 2014). Nevertheless, at its core, sustainable management of natural resources (NRM) relies on well-structured policies as well as effective institutional governance and cooperative resource users that in the long-term are all aiming for sustaining and strengthening the functional capacity of the SES surrounding the NRM (Holling, 2001; Ostrom, 2009; Epstein *et al.*, 2015; Liu *et al.*, 2015). The governance structure should preferably be multi-level and cross-sectoral and benefit from the integration of traditional knowledge and financial and institutional support (e.g., Reed *et al.*, 2016). Furthermore, according to Sayre *et al.* (2013), governmental policy decisions related to natural resource management should be based on human-nature management approaches that ensure that key social, ecological and abiotic components are included in the decision-making process. The sustainability of SESs depends in part upon the type of problems they are meant to address (scale), the contexts in which they operate (interplay) and on the fit between institutions (Epstein *et al.*, 2015). Each social-ecological system surrounding natural resource utilization is a unique niche and must be managed as such, and thus no panaceas are applicable for SESs governance and management (Ostrom, 2007; Sayre *et al.*, 2013).

The scope of the SES investigated at any given time depends on the specific question (empirical or policy) under consideration (McGinnis & Ostrom, 2014) and the strategic planning for achieving and/or maintaining sustainability within the SES needs to be based on a thorough overview of the system´s structure and insight to its functions. Furthermore, pre-defined plans on how to adapt to sudden or unforeseen changes are also needed for ensuring progress (McGinnis & Ostrom, 2014; Carpenter & Gunderson, 2001). According to Ostrom (2007) the long-term goal of an SES analysis should be to identify which combination of variables are most likely to lead to sustainable, but also productive use of given resource systems, and which combination potentially increases the risk of overexploitation with potential ecosystem collapse and high costs for society. Thus, to understand the complexity of an SES, a conceptual framework for system analysis is a fundamental tool.

Several conceptual frameworks have been designed for unpacking and analyzing the structure and functions of SESs. In this thesis, the SES framework (SESF) designed by Ostrom and colleagues (Ostrom, 2007; McGinnis & Ostrom, 2014) was used as criteria to unpack the first tier of the SES of rangeland management in Iceland, that is, its main structure and functions. According to Binder *et al.* (2013) the SESF is a general framework that works well for selecting the variables that are necessary to describe the interactions and dynamics in social and ecological systems akin to the one under investigation in this thesis. Binder *et al.* (2013) also argued that frameworks such as the SESF are well suited to study complex social-ecological issues where dynamic perspective on the social system and its interaction with the ecological system are involved. Although in this thesis, the framework was only used to highlight the rangeland SES´s outlines, the next section describes further what the framework stands for.

The Social-Ecological System framework

The Social-Ecological System Framework (SESF) is derived from the Institutional Analysis and Development Framework (IAD) (McGinnis & Ostrom, 2014). McGinnis and Ostrom (2014) stated that the original inspiration behind the SESF was to develop a diagnostic tool that could be used to understand the determinants of sustainability in multitier and complex SESs. The SESF has its disciplinary origin in political science and is based on theories such as common-pool resources, collective choice and natural resource management (Ostrom, 2009). The framework can be used to unpack the multitier hierarchy of all subsystems of an SES and reveal the interconnections between them (Binder *et al.*, 2013). The SESF provides a way to detect how the attributes of a resource system, the resource units produced/supported by the system, the actors utilizing it and the governance system managing it, jointly affect the interactions and the SESs outcomes achieved each time (Figure 1). It can also be useful to a) capture foreseen and unforeseen feedbacks that indirectly affect the interactions between the attributes of the SES under investigation, b) provide a way to reveal how these may affect and be affected by other political and socio-economic settings surrounding the SES and c) how the SES is connected to or is a part of other larger or smaller SESs (Ostrom, 2007).
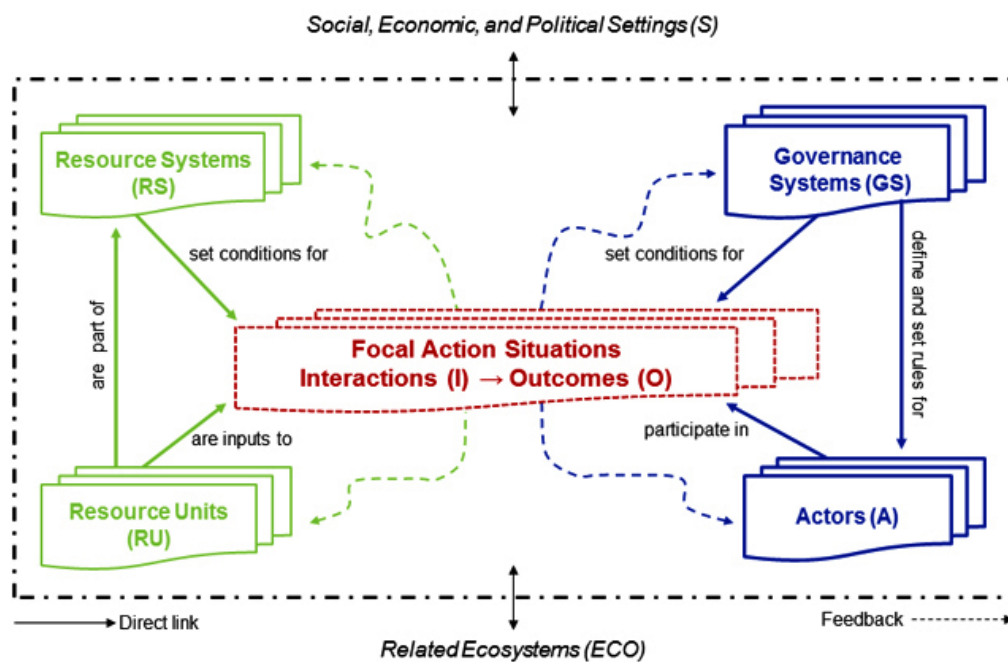
Figure 1. The Social-Ecological System Framework, from McGinnis and Ostrom (2014).

The first-tier categories of the SESF distinguish the ecological systems (resource system and resource units), the social systems (governance system and actors) and the interactions and outcomes (the focal action situation) within the SES. It is a decomposable system so each of the first-tier variables can be unpacked further into multiple conceptual tiers and more fine-grained variables (Ostrom, 2007; Binder *et al.*, 2013). The focal action situation is the core of the SESF; where individuals or agents of formal organizations interact and jointly influence or affect outcomes that are differently valued by each actor (Ostrom, 2009).

Good governance practices in natural resource management

Good governance practices are a necessary prerequisite for effective management of natural resources such as rangelands (e.g., Reed *et al.*, 2016; Richardson & Lefroy, 2016; Barwick *et al.*, 2014). Good governance means that procedures and processes of institutions provide results that meet societal needs while making the best use of the resources through sustainable management of natural resources, focusing on environmental protection (UNESCAP, 2009). Lockwood *et al.* (2010) presented a set of eight good governance principles, designed to provide normative guidance for NRM governance (Table 1).

Table 1. The eight principles for good governance practice in NRM as defined by Lockwood *et al.* (2010).

No.	Principle	Refers to	Further explanations
1	**Legitimacy**	• Validity of organization´s authority to govern. • Power devolved to the lowest effective level • Integrity with which authority is exercised	• A key factor in the effectiveness of governance arrangements • Conferred by democratic statue or earned through stakeholders´ acceptance
2	**Transparency**	• Visibility of decision-making process • Clarity with which the reasoning behind decisions is communicated • Availability of relevant information about governance and performance	• Decisions about NRM priorities and investments should be accessible • Clear who has made a decision, the means by which it has been reached and its justification
3	**Accountability**	• Allocation and acceptance of responsibility for actions and decisions • Demonstration of how responsibilities have been met	• Compliance with regulatory requirements is an important component of good governance for a public entity.
4	**Inclusiveness**	• Opportunities for stakeholders to participate in and influence decision-making action and processes	• All with a stake in governance processes can equally engage • Should be practiced in design of the governance system itself
5	**Fairness**	• Attention and respect given to stakeholders´ views • Consistency, excluding personal biases in decision-making	• Advancing NRM arrangements are expected to be equitable and fair in the exercise of the authority conferred on them
6	**Integration**	• Coordination across and connection between different governance levels and between organizations at the same level of governance • Alignment of plans, priorities and activities across governance organizations	• Requires institutional arrangements that can link separate informal and formal NRM institutional processes both horizontally and vertically • Policy and management instruments should be horizontally consistent across NRM sectors and organizations
7	**Capability**	• The systems, resources, plans, skills, leadership, experiences and knowledge that enable organizations, and the individuals who manage them, to effectively deliver on their responsibilities	• Complex problems are characterized by uncertainty, long time scales, diverse values and multi-dimensionality • Knowledge management is a key component for developing solutions to complex problems
8	**Adaptability**	• Incorporation of learning and new knowledge into decision-making and implementation • Anticipation and management of opportunities threats and associated risks • System reflection on organizational, individual and system performance	• Ability to rearrange internal processes and procedures in response to changing external or internal conditions • A strategic, anticipatory innovative, and forward-looking organization, capable of reading the external environment; reducing unexpectedness and surprises; demonstrate foresight; respond to and cope with change and adapt to changing community needs

Evaluating the progress of policies and practices

Sustainable management solutions to resource utilization must be compatible with the current, surrounding social and ecological conditions and their expected future changes (Chapin *et al.*, 2009). Evaluation is an assessment of any kind of activity that focuses on expected and achieved accomplishment, examines the processes, contextual factors and causality in order to clarify achievements or the lack thereof (UNEG, 2016). An effective evaluation of the governance of natural resource management is a precondition for systems´ improvements in the context of change (Rauschmayer *et al.*, 2009). Thus, it´s crucial to regularly evaluate both the governance process and its outcomes. Process oriented and outcome-oriented evaluation are multi-criteria approaches that both are important sources of evidence of the evaluated activity's achievements and contributes to knowledge building and organizational learning (UNEG, 2016). A process evaluation is undertaken to assess the internal governance process, complementary to assessing management effectiveness and, if needed, use the results to make adjustments to the management strategies and practices (OECD, 2009; Lockwood, 2010). Outcome evaluation, on the other hand, assesses the short term and/or the long-term impacts of a program or a project and should objectively estimate the relative contributions of the respective policies and processes to observed environmental and social change.

The information provided by an evaluation depends on the scope and the scale of the evaluated projects, programs or policies (Fitzpatrick *et al.*, 2011). Evaluation of a single project is made on a fine scale, meant to provide rather detailed information for that particular project's progress. But when evaluating a broad scale activity, like the impact of certain policies or national programs, the results should give an overview of their general progress and provide guidance to future policy related activities. Pre-set policies contain targets and milestones to the desired goals that can be used as evaluation signals; that is, to evaluate whether the inputs and the governmental system have effectively triggered the desired development (Fitzpatrick *et al.*, 2011).

An evaluation of natural resource management processes and outcomes should reveal if the respective governance system is well interconnected and functioning in accordance to the standards of good governance (Table 1, Lockwood *et al.*, 2010). Furthermore, an evaluation of such governance processes should provide information about, learning from, and suggestions for processes improvement, so as to enhance the fit between policies, the fit between the administrative structures that sustain the processes, and the attributes of the SES they address (e.g., Young, 2002). An evaluation of governance processes must refer to three elements, the process itself, its outputs and consequences (Figure 2). If the governance processes can be considered satisfactory, i.e., in accordance to the NRM principles for good governance practices, the process may reduce certain uncertainties and that way increase the reliability of an outcome-oriented evaluation (Rauschmayer *et al.*, 2009).
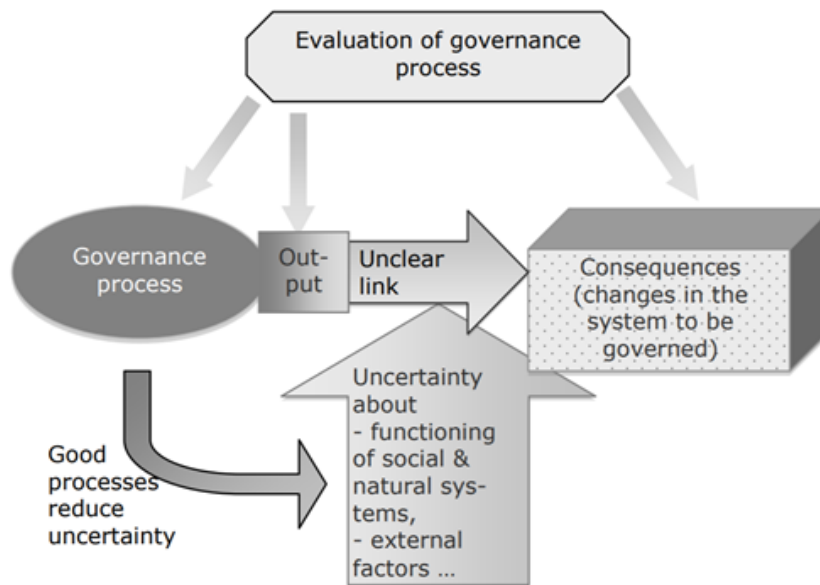
Figure 2. A framework for evaluating governance processes (derived from Rauschmayer *et al.* 2009).

According to Rauschmayer *et al.* (2009), there are four main themes that need to be covered in a governance evaluation: 1) *knowledge management*, referring to the multiple ways various knowledge is translated and integrated and how issues of ignorance and uncertainty are addressed; 2) *social dynamics*, referring to the level of active stakeholders´ involvement in participatory processes at various administration levels; 3) *legitimacy* that combines process and output related indicators and deals for instance, with transparency, representation issues and accountability and; 4) *effectiveness* referring in particular to outcomes and the state of the governed system.

To sum up, sustainable utilization of natural resources requires that the governing authorities and related stakeholders within the relevant SES: a) are practicing good governance, connecting and interacting within the respective SES; b) have an understanding of human-nature management approaches and know how to apply them; and c) regularly implement evaluations for all actions to analyze if the governance processes and outcomes are facilitating and or maintaining sustainable uses of natural resources, in line with stated tasks (Richardson & Lefroy, 2016).

SESs structure and functions and rangeland management

In cases where resource systems are degraded, such as the case of rangeland management covered in this thesis, a SES analysis is highly applicable for identifying underlying factors that might be driving the degradation processes and for providing solutions to reverse the degradation, for instance, through improved management practices and ecosystem restoration. An ecosystem restoration activity is a human-nature driven process, controlled by its own interconnected social and ecological systems, although the process is embedded in a larger and more complex process of natural resource management, such as of rangeland utilization. The SES surrounding the ecosystem restoration activity

thus might include a slightly different group of agents and actors than the larger SES of rangeland utilization, although the core group may be the same. To manage an SES of degraded resource systems towards long-term sustainable utilization, the diverse social-ecological processes, elements and variables driving or preventing ecosystem restoration need to be clear to the majority of actors involved. The respective governance system must set clear goals and targets in cooperation with the actors involved about how the ecological condition of these systems could be improved/restored.

In this thesis, the interconnected social and ecological system of rangeland management in sheep farming in Iceland was explored. The SESF was used to unpack the system, with the aim of highlighting the system´s first-tier variables and the findings used to map the system´s structure and further analyze its functions. As each Icelandic municipality that has rangelands within their territory has its own self-governing system surrounding local rangeland exploitation (Stefánsson, 2018), a more detailed SES analysis of the rangeland management system´s second tier variables were not applicable in the context applied here. The SES of Icelandic rangeland utilization for sheep grazing is embedded in a larger SES of livestock farming that is again embedded in still larger SES of natural resources and their utilization. A number of actors other than sheep farmers utilize the rangelands, including the tourism industry, electricity generating companies and the public. Even though these sectors are increasingly claiming rangelands for other utilization, such as hydropower production, biking, tourism and various forms of outdoor recreations; sheep grazing is still by far the most widespread practice.

The Icelandic rangelands are marginal lands that in previous centuries could only be exploited to benefit human livelihood via livestock grazing (Arnalds, 2005). Free roaming of sheep is an institutional setting that stretches as far back as to the arrival of the first Icelandic settlers, more than 1100 years ago (Ingimundarson, 2010). Most municipalities where sheep farming is practiced have commonly or collectively owned rangelands that are utilized for summer grazing. These areas are a) commons where landowners within a pre-defined neighborhood area are permitted to graze their livestock and b) collective rangelands, owned and utilized by more than one landowner. More than half of all Icelandic ecosystems are estimated to be in a degraded or eroded condition, most of which are classified as rangelands that are annually grazed by free roaming sheep during summertime (Arnalds & Barkarson, 2003). Sheep grazing on degraded rangeland systems is seen as the largest risk factor that may be limiting or preventing ecological succession within degraded areas and in some cases, the current grazing pressure might even be driving further ecosystem degradation (Arnalds, 2019).

Since 1990, several agricultural laws and regulations aiming at sustainable rangeland management have been approved by the Icelandic government. At the same time, the government initiated several new programs and projects to facilitate improved rangeland management and -restoration (e.g., Arnalds, 2005). Here, I will highlight two of these programs that are widely discussed in this thesis, the *Farmers Heal the Land* (FHL) program and the *Quality Management in Sheep Farming* (QMS).

The first governmental program with a clear aim of increasing stakeholder involvement in rangeland management was the cost-share voluntary program *Farmers Heal the Land* (FHL). It was established in 1990 by the SCSI with the prime objectives of encouraging land restoration, promoting cooperation and enhancing trust between farmers and authorities and facilitating behavioral changes in support of SLM practices (Arnalds, 1999; Arnalds, 2000). A few years later, the Icelandic government designed criteria for what should be considered as sustainable land management for sheep grazing and made it a compulsory pillar to the cross-compliance scheme, *Quality Management in Sheep Farming* (QMS). The scheme came into force in 2003 when the Legislation for Quality Management in Sheep Farming was approved (Arnalds and Barkarson, 2003). Sheep farmers participate in the scheme on a voluntary basis but those who fulfill its requirements of sustainable land use and good farming practices receive almost 30% higher subsidy payments for their lamb meat production compared to non-participating farmers (Karlsson *et al.*, 2015; Þorláksdóttir, 2015).

Objectives of the thesis

Improved rangeland management and ecosystem restoration of severely degraded rangelands have been official policy targets of the Icelandic government for over three decades. Several agricultural and environmental policies were developed during this period, supported by laws and regulations. In line with the policy goals, various agri-environmental programs and projects intended to facilitate behavioral changes among rangeland users towards sustainable grazing management were established. Nevertheless, the overall progress of the policies and all related programs and projects has never been examined, nor has the expected long-term progress of the governance practices been evaluated in a comprehensive way.

The aim of this thesis was to examine through a research on rangeland management and restoration in Iceland if the expected long-term progress of identified policy goals and all related programs and projects had been achieved. Main objectives were to explore the SES of large-scale rangeland restoration in Iceland with a focus on the system's main stakeholder groups and their interrelationships to investigate the possible effects of social factors on restoration outcomes; conduct a summative evaluation for a large-scale restoration program to identify its performance and long-term social-ecological attainments at a national scale; explore the institutional arrangements related to rangeland grazing management at a national level; and analyze the sustainability consequences of the governance and resource management approaches applied within the system.

Summary of investigations

The research has resulted in four published scientific papers. The first paper analyzed the drivers for ecological restoration in Iceland for the last 100 years, if the drivers have changed over time and if so, due to what factors. The second paper explored the social-ecological system of large-scale rangeland restoration in Iceland to investigate the possible effects of social factors on restoration outcomes. The third paper included a summative evaluation comparing the attitude and behavior of farmers towards rangeland management and rangeland restoration, based on whether farmers were participating in the Farmer Heal the Land restoration project or not. The fourth paper included an overview of the administrative structure that steers rangeland management in Iceland, followed-up with a critical analysis of the governance system´s structure and functions to examine if agricultural and environmental policy targets have facilitated improved rangeland management practices.

Materials and methods

Paper I is based on a comprehensive review of ecological restoration in Iceland published in Icelandic and edited by Aradóttir & Halldórsson (2011). The review contained a detailed summary of past and ongoing restoration activities collected from public agencies, nongovernmental organizations, private companies, municipalities, and other restoration actor groups. The restoration projects included were selected by a group of restoration experts based on the definition of ecological restoration as described by the Society for Ecological Restoration (SER, 2004). The catalogue included in total 100 restoration projects, programs, and areas, representing 75% to 85% of all restoration activities in Iceland. The summary also included a catalogue of known current and past ecological restoration research projects, a policy framework review and background information on land degradation. This information was collected from secondary data, previously published in peer reviewed papers, reports, articles and relevant policy documents issued by ministries and governmental agencies. The drivers for the restoration projects and their order of importance were determined based on information from the responsible actors and agencies for different time periods, reports and other published records. The drivers were broadly categorized into socioeconomic drivers, environmental drivers, and policy drivers. Ecological restoration areas were categorized by their dominant habitat type and the average score for each driver within each time period calculated. As the scoring was value based, the data could not be analyzed any further.

Paper II is based on interviews with preselected stakeholders involved in rangeland management. Ten sheep farmers and five officials participated and were interviewed in two separated qualitative surveys. All the participants were asked about their attitudes toward soil conservation, land use, ecosystem restoration and agri-environmental policies. The interviewed sheep farmers were selected from two rural municipalities (Skaftarhreppur in the South and Skutustadahreppur in the North) that both rely strongly on sheep farming and tourism and have severely degraded ecosystems that in some cases are still under the threat of soil erosion. Local SCSI district officers identified and contacted sheep farmers that fulfilled the main selection criteria for the survey (owning >200 adult sheep; participating in the Farmers Heal the Land restoration program; dissimilar attitudes toward land use and restoration). In the second part of the study, five officials were defined as key informants. All of them were directly involved in policy settings for agri-environmental topics and all held high ranking management positions within the agricultural or the environmental sectors. The participants were visited at their offices and interviewed. The interviews were semi-structured, following a list of open-ended questions based on the preselected topics. The results from both parts of paper II were divided into three categories: (a) Land use/Restoration, (b) Collaboration, and (c) Governance and used as a setup for a table where each participant's attitude was roughly ranked, based on his/her view in comparison with

the other participants' views on the same category. Symbols were used to distinguish among their attitudes. The symbol "+" signified a positive view, the "-" a negative view and the "0" a neutral view. Two symbols of the same type expressed a stronger view.

The results from Paper II were used to structure and phrase the questions of a survey presented in Paper III and IV. The survey was distributed to all sheep farmers that were members of the Icelandic Sheep Farmer´s Associations at the time, and to the staff of agricultural and environmental institutions (including the ministries) and agencies in Iceland, that have a direct role in rangeland management. The survey was also distributed to all parliamentarians at that time and members of local authorities in municipalities that the State had defined as depending on sheep farming in the socio-economic context. A hard copy of the survey was mailed to in total 1261 farmsteads or 87% of all registered sheep farms in Iceland at that time (Icelandic Agricultural Statistic, 2010). In addition, 503 officials received an e-link to an online version of the survey. The survey was posed with the permission from the Icelandic data protection authorities.

In Paper III, selected questions from the survey were used to evaluate if the FHL programme had facilitated perceptional and behavior changes among the participating sheep farmers, in accordance with its objectives. The selected questions were intended to measure the attitude of the participants in the survey towards rangeland management and restoration approaches, their perception of state support and collaboration and if they had acknowledged the need for improved grazing management and accordingly changed their rangeland grazing patterns. A conceptual framework, listing the anticipated outcomes to the questions of the survey, was used to evaluate if the farmers held values consistent with the initial objectives of the FHL programme. If the observed and the anticipated outcomes matched, it was considered to indicate that the FHL had facilitated changes in perception or behavior among its participants. A Wilcoxon–Mann–Whitney, non-parametric test (Townend, 2009) was used to compare the replies from FHL and non-FHL farmers. In cases where the Mann–Whitney test showed a difference between the FHL and non-FHL farmers, the replies were analyzed in more detail with a propensity scoring matching (e.g., Rubin, 1974). A principal component exploratory analysis was done to check if there were some underlying factors influencing the replies and a Friedman test was used to estimate if the ranking of the replies to selected questions was identical. Furthermore, a chi-square test was used to compare the replies from the FHL and non-FHL farmers to questions related to rangeland management and restoration practices.

In paper IV, the formal administrative structure of the governance system for rangeland management in Iceland was mapped with the use of information from respective webpages and secondary data sources (Table 2). Furthermore, selected questions from the previously mentioned survey were used to estimate if the respective environmental and agricultural policy targets had facilitated sustainable rangeland management practices as intended.

Table 2. Hierarchical and structural locations of people within the agri-environmental governance system, identified by the authors of this paper to have a role in rangeland management. Those that regularly are in "face to face" contact with farmers in their work are considered to have direct interactions with them, those that irregularly or even never meet with the farmers are considered to have indirect interactions with them (Paper IV).

Position	Role	Interactions with farmers	Institute/ institution/ organization
Parliamentarians	Elected members of the Icelandic parliament. National policies and laws	N/A	National assembly
Ministry experts	Administration and communication to all related stakeholder groups and institutes. Preparing laws and regulations for approval and implementation	Indirect	Ministry for Environment and Natural Resources and Ministry for Industry and Innovation (incl. agriculture)
Aldermen (regionals)	Elected member of regional authorities. Local administration and decision making, regional policy design and implementation	Indirect	Regions, defined by the state to highly depend on sheep farming
University lecturers/professors	Research and consultancy in her/ his field of expertise and providing education in agricultural and/or environmental science to students	Indirect/direct	Agricultural University
Agricultural advisors	Advising farmers on livestock breeding, livestock husbandry, agronomy and farm accounting	Direct	Farmers Association Icelandic Agricultural Advisory Centre
Agricultural experts/managers	Administration and interest monitoring for the agricultural sector	Indirect/direct	Farmers' Association Icelandic Agricultural Advisory Centre
Environmental advisors	Advising farmers on rangeland grazing and ecosystem restoration, supervisory of land condition	Direct	Soil Conservation Service
Environmental experts/managers	Administration, monitoring of land condition, control of land management, diverse research focusing on terrestrial ecosystems	Indirect	Soil Conservation Service, Forest Service, Institute of Natural History, National parks
Afforestation advisors/park rangers	Advising farmers/landowners on forestry, planning and monitoring afforestation projects/ controlling of protected areas	Direct/indirect	Forest Service, National parks

The questions used in the paper explored the attitude of participants in the survey towards rangeland management; their perception on the level of state support, and collaboration for rangeland restoration; their views on current policies related to rangeland management and what authorities should be involved in designing and implementing policy targets concerning rangeland management. A Wilcoxon-Mann-Whitney, non-parametric test (Townend, 2009), was used to compare all replies divided by sectors and a Friedman test was used to assess whether the ranking of the replies across

all sectors were identical, performed independently for each sector. Additionally, the principles of good governance practices and evaluation in NRM (Lockwood *et al.*, 2010; Rauschmayer *et al.*, 2009) were used as criteria in the discussions to examine, based on the overall outcomes from the research, if the governance system of the rangelands´ management is structured and functions was in accordance to the principles.

Main findings

Paper I showed that throughout the 20th century, halting of soil erosion and protection of vegetation and soils were the strongest environmental drivers for heathland/grassland restoration, but nature conservation and ecological restoration were the strongest environmental drivers for woodland restoration. The provision of wood and grazing land were important socioeconomic drivers for woodland and heathland/grassland restoration, but other socioeconomic drivers, such as mitigation associated with the construction of hard infrastructure (roads and power plants), came into play in the 1970s (Figure 3). In the 1990s, new drivers, for instance carbon sequestration in vegetation and soils, came also into play as a part of the governmental policy to comply with the United Nations Framework Convention in Climate Change (UNFCCC) commitments, (Figure 3).
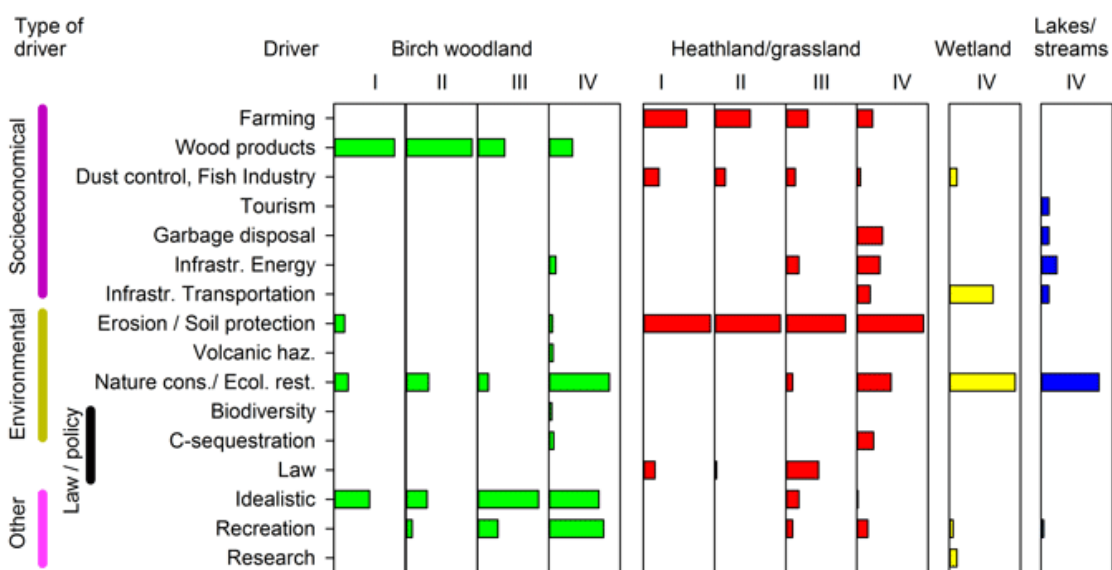
Figure 3. Average score of main drivers of ecological restoration in Iceland by habitats and periods; I: 1907-1930s, II: 1940s-1960s, III: 1970s-1980s, IV: after 1990 (Paper I).

In the context of land use/restoration, the main findings of Paper II showed that the interviewed farmers usually acknowledged the importance of soil protection and restoration. They also claimed that rangeland management had improved since 1990, mainly due to shorter annual grazing period and reduced grazing pressure given the decrease in the number of sheep. The farmers mentioned that the development of strong agri-environmental advisory service since 1990 had sensitized the sheep farming sector about the degradation risk from early spring and winter grazing. In the farmers´ opinion, the restoration support system offered by the SCSI had in particular raised awareness among farmers about how rangeland management could be improved. Ethical values, such as respect and care for the land and ecosystem improvements, were most commonly mentioned by the farmers as a motivation to practice restoration, but most of them did not cite economic reasons as being of importance (Table 3).

Table 3. Overview of the participants´ attitudes on land use/restoration, collaboration governance (Paper II).

Farmers	Profession	Location	Land use/restoration	Collaboration	Governance
1	Sheep farmer	Skaftarhreppur	0	0	0/-
2	"	"	++	+	+/-
3	"	"	++	++	0
4	"	"	++	++	+/-
5	Sheep/Dairy farmer	"	++	++	++
6	"	Skutustadahreppur	++	+	0
7	Sheep farmer	"	++	+	+
8	"	"	++	+	+/-
9	"	"	++	+	+/-
10	"	"	++	++	++
Officials					
1	Director	Reykjavik	++	++	+/-
2	Parliamentarian	"	++	++	++
3	Director	"	++	++	+/-
4	Director	"	++	++	+/-
5	Director	"	++	+	+/-

The interviewed officials claimed that sustainable land management was an important factor in maintaining healthy ecosystems, and that ecosystem restoration was a useful approach to improve the condition of degraded ecosystems (Table 3). The officials working in the agricultural sector presented more agronomic based perspectives toward restoration outcomes and claimed that restoration activities should primarily be aimed at optimizing land use. In contrast, interviewees working in the environmental sector presented more ecologically oriented views, highlighting the importance of restoring ecosystem services and conserving biological diversity. They also mentioned Iceland´s obligations to fulfill its commitments under international conventions.

In the context of collaboration, restoration activities seemed to have stronger social value among the interviewed farmers in Skaftarhreppur than in Skutustadahreppur. Some of the farmers in Skaftarhreppur volunteered in restoration projects and most of them were also active members of the local restoration NGO (Landgræðslufélag Skaftarhrepps). The farmers in Skutustadahreppur worked individually on restoration on their private land, usually in collaboration with the SCSI. Compared with the farmers in Skaftarhreppur, the farmers in Skutustadahreppur did not seem motivated to participate in voluntary work outside the farm (Table 3) and their restoration activities appeared to be more related to the availability of direct incentives, such as funding support. All the interviewees felt that restoration projects have to some extent both social and ecological importance and should be designed and implemented in collaboration between stakeholders. They also felt that all ecological restoration projects should get strong financial support from the state, irrespective of who owns the degraded land in question. The interviewees favored the use of participatory approaches in restoration, stating that such approaches lead to stronger consensus among all involved in the process and more efficient outcomes than from a top-down approach (Table 3).

In the context of governance, some of the farmers felt that the connections between farmers and agri-environmental agencies were not strong enough to establish mutual trust and the officials were often lacking a deeper insight into sheep farming and country life. The interviewees generally claimed that there was a lack of comprehensive government policy focusing directly on sustainable land management as its main goal. Some of the officials mentioned that the perceived policy gap had given the agencies too much space for individually shaping their own policy targets. In some cases, the agencies focused on achieving single targets (such as entering into new activities without a formal legal approval) that over the years became accepted by the national government as parts of the state´s legislations. This development seemed to have caused friction between governmental agencies and obscured which one was the leading authority within a given scientific or policy field.

Many of the officials felt that the government should set a broad trans-sectoral designed policy framework, within which the governmental agencies could shape their policy targets. Nevertheless, they were unsure whether the government would have the courage or the political strength to create such a comprehensive policy framework due to a strong opposition against it among many stakeholder groups. The officials viewed the agricultural and the environmental sectors as two separated entities. In their opinion, the environmental and agricultural agencies and ministries were often not receptive to cooperation or transparent discussions on joint topics, operating too often in an institutionally "self-centered" manner. According to them, this "silo mentality" most likely has significantly limited the overall institutional efficiency in the agri-environmental field. On the one hand, the agricultural officials felt that the 2008 transfer of the SCSI from the Ministry of Agriculture to the Ministry of Environment had weakened the ties between the two sectors and could lead to even further policy fragmentation in the agri-environmental field. The environmental officials, on the other hand, believed that the transfer would sharpen the public focus needed for applying ecological approaches to land restoration.

Paper III is based on replies from the farmers that received a copy of a survey asking about their opinions and behavior concerning rangeland management and restoration (Table 4).

Table 4. The distribution of the survey sample and respondents, by regions and FHL membership (Paper III).

Region	Sent surveys /Replies	Answering rate (%)		FHL (%)	non-FHL (%)
West	347/126	36	40		60
North	319/108	34	44		56
East	276/130	48	57		43
South	319/103	32	44		56
Not usable	/13	-	-		-
Overall		37	46		54

The majority of the farmers that replied were practicing restoration because they wanted to improve land quality and/or to expand available grazing land and because they felt it was their moral responsibility (Table 5). The majority of the participants also stated that restoration should focus on restoring native vegetation and improving soil quality, mainly by applying organic matter to degraded areas. Nevertheless, less than half of them wanted to limit the application of mineral fertilizer to minimum doses (Table 5). Significantly more FHL farmers (than non-FHL farmers) stated that one of the main purposes of restoration was to expand the size of grazing areas ($Z = 3.05$; $p < 0.005$). They favored the use of grass seed in restoration ($Z = 3.51$; $p < 0.0005$) compared with non-FHL farmers and were not in favor of fencing off degraded areas to facilitate spontaneous recovery ($Z = -5.23$; $p < 0.0001$). Significantly less FHL farmers than non-FHL farmers favored grazing exclusion of restoration areas ($Z = -5.91$; $p < 0.0001$), and significantly more FHL farmers claimed that any grazing limits were unnecessary ($Z = 4.75$; $p < 0.0001$) (Table 5).

Table 5. The relative ranking (%) of respondents' attitude towards rangeland restoration practices (category 1). Those who neither agreed nor disagreed are excluded (Paper III).

Attitude towards rangeland restoration	FHL Disagree	Agree	Non-FHL Disagree	Agree	Anticipated outcome	Observed outcome	Match
Why do you practice restoration:							
a) Out of interest for improving the land's qualities	1	95	1	95	N/A	N/A	N/A
b) It's my moral responsibility	4	87	4	83	N/A	N/A	N/A
c) It gives additional income	16	45	18	39	A	N/A	N
d) To increase the size of usable grazing land*	1	82	1	75	A	A	Y
The purpose of rangeland restoration is foremost to:							
a) rebuild damaged ecosystems	2	89	1	88	A	A	Y
b) restore vegetation and soil qualities	0	97	0	96	A	A	Y
c) make the appearance of the land green again	1	86	4	85	D	A	N
When restoring damaged rangeland it is best to use:							
a) minimum doses of inorganic fertilizer	26	44	19	50	A	A	Y
b) Fence the area and spontaneous succession*	58	14	33	28	A	D	N
c) organic matter like sheep manure and hay	1	96	0	92	A	A	Y
d) grass seeds with first fertilizer treatment*	5	73	12	65	D	A	N
e) a sheep-proof fence and sow Alaska lupine	52	19	61	17	D	D	Y
Restoration of damaged rangeland should lead to:							
a) grazing tolerant vegetation	1	91	2	86	A	A	Y
b) increased soil quality	0	97	0	96	A	A	Y
c) succession of native local vegetation	1	83	3	81	A	A	Y
d) vegetated land, regardless of species composition*	26	55	31	40	D	A	N
Grazing of treated areas should be limited to:							
b) areas under restoration should not be grazed*	63	10	36	25	A	D	N
c) **there is** no need to limit grazing during restoration*	43	25	62	12	D	D	Y

The anticipated and the observed outcome of each question are symbolized with "A" (Agree) or "D" (Disagree). Matching letters indicate that the FHL program had facilitated paradigm shift or behavior changes among its participants (Y = yes; N = no; N/A = not applicable) (Table 1). * indicates where the Wilcoxon test showed a significant difference in the mean rankings of the FHL and the non-FHL (P<0.05). FHL = farmers participating in the Farmers Heal the Land program (N = 224), non-FHL = farmers not participating in the FHL (N = 243).

The majority of all participants did not want to restrict the grazing period at the highland commons from mid-June to end of August and opposed the statement that the highland's commons should preferably be protected from grazing, even though around 60% of the participants did not support grazing on poorly vegetated land. The participants were not highly supportive of lowland grazing during summer, favoring instead the current system of free roaming sheep grazing on highland commons or collectively own areas (Table 6).

Table 6. The relative ranking (%) of respondents' attitude towards rangeland management (category 2). Those who neither agreed nor disagreed are excluded. (Paper III).

Attitude towards rangeland management	FHL Disagree	Agree	Non-FHL Disagree	Agree	Anticipated outcome	Observed outcome	Match
						FHL/non-FHL	FHL/non-FHL
Grazing period in the highland commons':							
[a)] never before mid of June	51	28	45	34	A	D/D	N/N
[b)] never longer than till end of August	81	5	77	5	A	D/D	N/N
Sheep grazing shall be practiced on:							
[a)] currently grazed areas	6	70	5	72	D	A/A	N/N
[b)] highland commons that, according to research have sufficient carrying capacity	3	85	3	82	A	A/A	Y/Y
[c)] collective fenced areas in the lowland	49	27	45	31	A	D/D	N/N
[d)] fenced, privately owned lowland	43	42	40	43	A	N/A	N/N
[e)] richly vegetated areas, regardless of location	27	46	23	50	A	A/A	Y/Y
It is acceptable to graze rangeland in the lowland:							
[a)] when the vegetation has started to grow	1	95	1	97	A	A/A	Y/Y
[b)] never in winter	32	49	33	44	A	A/A	Y/Y
Land, suitable for sheep grazing:							
[a)] grassland and other well vegetated land	0	96	0	98	A	A/A	Y/Y
[b)] depends on experts' advices	27	24	32	22	A	N/A	N/N
[c)] cultivated land	14	69	12	69	A	A/A	Y/Y
[d)] poorly vegetated land should not be grazed	15	57	15	61	A	A/A	Y/Y
[e)] highland commons should preferably not be grazed	75	9	69	12	A	D/D	N/N

The anticipated and the observed outcome of each question are symbolized with "A" (Agree) or "D" (Disagree). Matching letters indicate that the FHL program had facilitated paradigm shift or behavior changes among its participants (Y = yes; N = no; N/A = not applicable) (Table 1). FHL = farmers participating in the Farmers Heal the Land program (N = 224), non-FHL = farmers not participating in the FHL program (N = 243).

Paper III also shows that more than half of the FHL farmers that participated in the survey treat new restoration areas with grass seeds and mineral fertilizer, compared to only 14% of the non-FHL farmers. On the other hand, 80% of the non-FHLs instead stated that they use organic residues (hay litter and/ or sheep manure) to mulch their restoration areas, compared with 65% of the FHLs. According to the survey, over 80% of all respondents grazed their restoration areas concurrently with restoration treatments. Similarly, more than 80% of both groups considered their farmsteads to be in a fairly good ecological condition (0-40% erosion rate). Significantly more FHL farmers, or 48% against 33% non-FHL farmers, believed that 20% or more of degraded areas within their farms could be restored.

Paper IV examined the structure (Figure 4) and functions of the governance system for rangeland management.
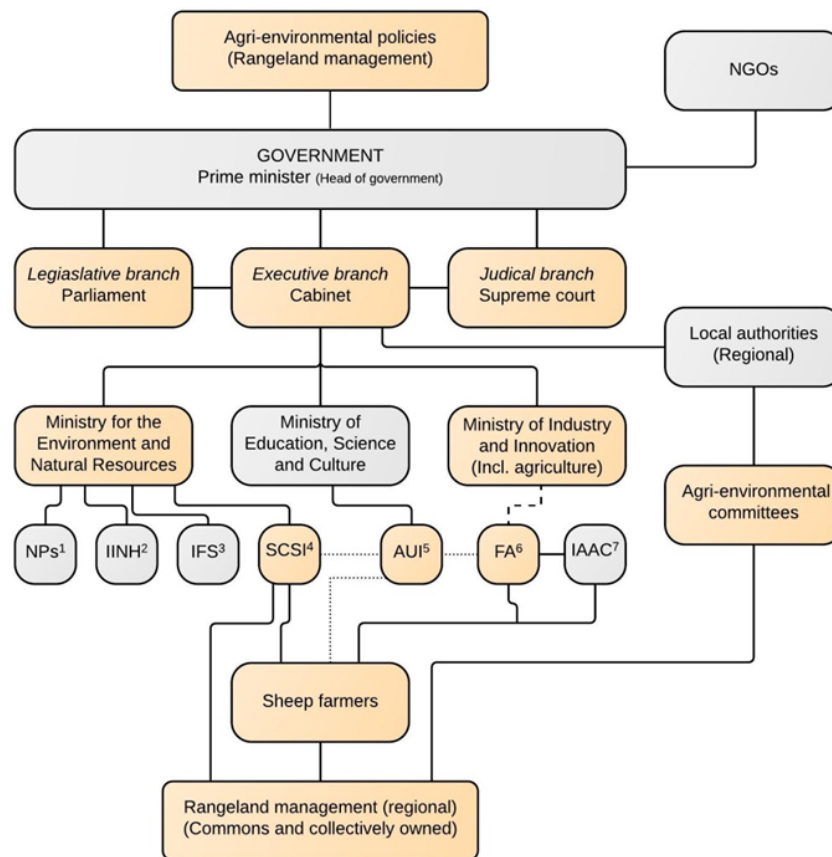
Figure 4. The political-administrative structure of the Icelandic governance system related to rangeland management. The beige colored boxes highlight those that play an active role in the process of designing and implementing agri-environmental policies for rangeland management, but the gray colored boxes show those that are less actively involved in the process. Solid lines indicate direct influence, dashed and dotted lines indicate indirect influence or connection (Paper IV). (NPs[1]= National Parks; IINH[2]= Icelandic Institute of Natural History; IFS[3]= Icelandic Forest Service; SCSI[4]= Soil Conservation Service of Iceland; AUI[5]= Agricultural University of Iceland; FA[6]= Farmers Association; IAAC[7]= Icelandic Agricultural Advisory Centre).

The mapping of the system revealed that all administrative activities concerning sustainable land management, including restoration and reforestation are under the auspice of the Ministry for Environment and Natural Resources (MENR), while all agriculturally based activities are under the auspice of the Ministry for Industry and Innovation (MII). Hence, the scientific and the professional knowledge for designing and following-up agri-environmental policies related to rangeland management and the official decision-making capacity within the agricultural subsidy system are managed separately by two ministries. The system mapping also revealed that no cross-sectoral team of policy experts focusing on all social-ecological aspects related to rangeland management exists and a formal agri-environmental transdisciplinary platform for knowledge application and decision-making is also lacking. The dashed line from the MII to the Farmers Association (FA) symbolizes an indirect administrative connection as the FA is a private business interest organization, only partially funded by the state. The system mapping

also showed that the AUI is only loosely linked to the policy process concerning rangeland management as it falls under the auspice of the Ministry of Education Science and Culture (MESC) without any formal land use policy-making connections to the MII. Authorities of the respective municipalities are embedded in the governance process of rangeland management as they hold jurisdiction over all communal lands within their territorial boundaries.

The second part of Paper IV is based on responses to a nationwide survey. A questionnaire was distributed online to 503 public employees working within the governance system related to rangeland management; 217 (43%) usable copies were returned (Table 7). The answering rate from the farmers was the same as introduced earlier, or 37%.

Table 7. Answering rate to the survey from various institutions and organizations, divided by sectors (Paper IV).

Name / Sector	Type	Level	Role	Sent surveys	Received replies	Reply rate (%)
National assembly /**Officials**	Parliament	National	National policies/laws/ democracy/cooperation	63	9	14
Ministry for environment and natural resources (MENR) / **Officials**	Governmental department	National	Administration/legislations environmental policies/ internation-al cooperation	21	6	29
Ministry for industries and innovation (MII) / **Officials**	Governmental department	National	Administration/legislations agricultural policies/ international cooperation	17	4	24
Municipalities/ **Local authorities***	District government	Regional	Administration/regional policies	131	57	44
The Agricultural University of Iceland (AUI) / **Education**	State university	National (MESC***)	Secondary and tertiary education/ research/policy inputs	65	18	28
The Farmers Association (FA) **Agricultural**	Business Interest organization	National	Administration/policy interest mon-itoring	50	64	65
The Icelandic Agricultural Advisory Centre (IAAC). **Agricultural**	Sister com-pany of the FA	National	Agricultural advisory	48	↑	↑
The Icelandic Institute of Natural History (IINH). **Environment**	Governmental institute	National (MENR)	Monitoring/research/policy inputs	20	76	70
National parks (NP)** **Environment**	Governmental agencies	National (MENR)	Control/information/policy inputs	17	↑	↑
The Icelandic Forest Service (IFS) **Environment**	Governmental institute	National (MENR)	Practice/control/advisory/ research/policy inputs	45	↑	↑
The Soil Conservation Service of Iceland (SCSI). **Environment**	Governmental institute	National (MENR)	Practice/control/advisory/ research/policy inputs	26	↑	↑

↑Symbolizes that all the replies from respondents within the agricultural sector were merged to one number; so were all the replies from respondents within the environmental sector
*Local authorities of all regions officially defined as economically depending on sheep farming
**All permanent staff of the Vatnajokull, Thingvellir and Snaefellsnes national parks
***Acronym for the Ministry of Education, Science and Culture

The statement that sheep grazing should be practiced on highland commons that according to scientific research results have sufficient carrying capacity got strong support from all sectors (Table 8). The environmental and the educational sectors were, however, in general more ecologically centered in their replies concerning rangeland management practices than the agricultural sector, local authorities and the farmers were.

Table 8. Mean rankings (1= strongly disagree – 5= strongly agree) of all agents (by sectors of profession; Table 7) and the sheep farmers´ attitude concerning how to manage sheep grazing on highland commons and other rangelands (Paper IV).

Attitude towards rangeland management	Education	Environment	Officials	Agriculture	Regionals	Sheep farmers
Length of the grazing period at the highland commons:						
a) Never before mid of June	3.9 [a]	3.8 [a]	3.4 [ab]	3.0 [b]	2.7 [c]	2.5 [c]
b) Never longer than till end of August	3.2 [a]	3.1 [a]	2.4 [b]	2.1 [b]	2.2 [bc]	1.9 [c]
Sheep grazing shall be practiced on:						
a) currently grazed areas	2.2 [a]	2.4 [a]	2.7 [ab]	3.1 [b]	3.8 [c]	3.9 [c]
b) highland commons that, according to research have sufficient carrying capacity	4.1 [a]	4.1 [a]	4.2 [a]	4.2 [a]	4.3 [b]	4.1 [a]
c) collective fenced areas in the lowland	3.7 [a]	3.7 [a]	3.8 [a]	3.0 [b]	2.7 [b]	2.7 [b]
d) fenced, privately owned lowland	4.0 [a]	3.9 [a]	3.8 [a]	3.5 [a]	3.1 [b]	2.9 [b]
e) in areas depending on sheep farming	2.7 [a]	2.8 [a]	2.9 [ab]	2.7 [a]	3.3 [b]	3.2 [b]
It's acceptable to graze rangeland in the lowland:						
a) until it starts to snow in the autumn	2.4 [a]	2.7 [ab]	3.2 [b]	3.2 [b]	3.5 [c]	3.3 [bc]
b) never in winter	3.8 [b]	3.9 [b]	3.6 [ab]	3.3 [a]	3.0 [a]	3.2 [a]
Land considered suitable for sheep grazing:						
a) grassland and well vegetated land	4.6 [a]	4.4 [a]	4.1 [a]	4.5 [a]	4.3 [a]	4.5 [a]
b) depends on experts' advices	4.1 [a]	4.0 [a]	4.0 [a]	3.5 [b]	3.4 [bc]	2.9 [c]
c) poorly vegetated land should not be grazed	3.9 [ab]	4.3 [a]	3.8 [b]	3.8 [b]	3.8 [b]	3.6 [b]
d) highland commons should preferably not be grazed	2.9 [ab]	3.1 [a]	2.7 [ab]	2.2 [b]	2.3 [b]	2.0 [b]

Education = agents working at the AUI (N = 18); Environment = agents working at the IINH, NPs, IFS and SCSI (N = 76); Officials = parliamentarians and agents working at the MENR and MII (N = 19); Agriculture = agents working at the FA and FAS (N = 64); Regionals = members of the local authorities within regions officially defined to be depending on sheep farming (N = 57) and sheep farmers (N = 467). Mean ranks within rows identified with the same superscript letter were not significantly different (P > 0.05).

The majority of all respondents perceived that there was good collaboration between farmers in joint restoration projects and felt that restoration activities were not forced by law and legislation (Table 9). Restoration was seen by over 60% of all respondents as a social obligation that the state should subsidize but the agricultural sector, the local authorities and the farmers were significantly less in favor of keeping restoration subsidies low than were the other two sectors (Table 9).

Table 9. Mean rankings of all employees (by sectors of profession; Table 7) and the sheep farmers´ attitude concerning collaboration and incentives in rangeland restoration (1= strongly disagree – 5= strongly agree). (Paper IV).

Attitude towards collaboration	Education	Environment	Officials	Agriculture	Local authorities	Sheep farmers
Collaboration in rangeland restoration:						
a) Farmers work cooperatively in restoration projects	3.9 a	4.2 b	4.1 a	4.3 b	4.2 b	3.9 a
b) Law and legislations force farmers to practice restoration	2.7 b	2.3 ab	2.4 ab	2.3 ab	2.4 ab	2.2 a
c) Good cooperation between farmers and SCSI	3.7 a	4.2 c	4.3 c	4.0 b	4.1 bc	4.0 b
d) The agri-environmental sectors are jointly planning restoration projects	3.5 a	3.4 a	3.6 a	3.4 a	3.5 a	3.3 a
Direct incentives for increased restoration:						
a) Restoration is a societal task the state should subsidize	3.9 ab	4.1 ab	3.7 b	4.2 a	3.9 ab	4.1 ab
b) Restoration subsidies should be low	3.2 b	3.0 b	3.2 b	2.7 a	2.7 a	2.6 a

Education = agents working at the AUI (N = 18), Environment = agents working at the IINH, NPs, IFS and SCSI (N = 76), Officials = parliamentarians and officials working at the MENR and MII (N = 19), Agriculture = agents working at the FA and FAS (N = 64), Local authorities = members of the local authorities within regions officially defined to be depending on sheep farming (N = 57) and sheep farmers (N = 467). Mean ranks within rows identified with the same superscript letter were not significantly different (P > 0.05).

Only around 10% of all respondents disagreed with the argument that state rangeland restoration policies lack focus and clarity of purpose, while close to 50% of the respondents agreed with the claim and around 40% of the respondents neither agreed nor disagreed. All sectors strongly supported the argument that municipalities should actively participate in designing restoration policies, and that environmental and agricultural institutes should follow a joint policy for sheep grazing and restoration (Table 10).

Table 10. Mean rankings of all employees (by sectors of profession; Table 7) and the sheep farmers´ attitude towards governance and policies concerning rangeland restoration and management (1= strongly disagree – 5= strongly agree) (Paper IV).

Attitude towards governance and policies	Education	Environment	Officials	Agriculture	Local authorities	Sheep farmers
Rangeland restoration:						
a) Should be managed at a regional level	4.1 [ab]	4.4 [a]	3.2 [c]	4.2 [a]	4.1 [ab]	3.9 [b]
b) Should be under the custody of the SCSI*	3.2 [a]	3.5 [a]	3.5 [a]	3.6 [a]	3.3 [a]	3.5 [a]
c) Should be under the custody of the FA*	2.6 [a]	2.7 [a]	2.5 [a]	3.1 [b]	3.3 [b]	3.3 [b]
d) Should be part of the compulsory curriculum for all studying agricultural science	4.3 [a]	4.5 [a]	4.1 [ab]	4.1 [ab]	3.9 [bc]	3.7 [c]
Rangeland restoration policies:						
a) Governmental policies are focused and clear	2.5 [a]	2.3 [a]	2.7 [a]	2.5 [a]	2.6 [a]	2.5 [a]
b) The FA actively participate in designing governmental rangeland restoration policies	3.1 [ab]	2.6 [a]	3.1 [ab]	2.8 [a]	3.2 [b]	3.1 [ab]
c) The government design rangeland restoration policies in collaboration with farmers/land users	3.3 [a]	3.1 [a]	3.8 [b]	3.3 [a]	3.3 [a]	3.2 [a]
d) The ministries for agriculture and environment <u>should</u> jointly form governmental restoration policies	4.2 [bc]	4.4 [c]	4.2 [bc]	3.9 [b]	3.9 [b]	3.6 [a]
e) Municipalities <u>should</u> actively participate in designing governmental restoration policies	4.2 [bc]	4.3 [c]	4.2 [bc]	4.1 [b]	3.9 [ab]	3.8 [a]
f) Agricultural and environmental institutes <u>should</u> follow a joint policy for restoration and sheep grazing	4.1 [bc]	4.3 [c]	4.2 [bc]	3.8 [b]	4.0 [b]	3.5 [a]

Education = agents working at the AUI (N = 18), Environment = agents working at the IINH, NPs, IFS and SCSI (N = 76), Officials = parliamentarians and officials within the MENR and MII (N = 19), Agriculture = agents working at the FA and FAS (N = 64), Local authorities = members of the local authorities within regions officially defined to be depending on sheep farming (N = 57) and sheep farmers (N = 467). Mean ranks within rows identified with the same superscript letter were not significantly different (P > 0.05).

Discussion

Main drivers for restoration

The historical overview of the main drivers for ecological restoration in Iceland for the last 100 years presented in Paper I revealed that catastrophic erosion was the main driver for the establishment of official soil conservation and restoration effort in Iceland in the early 1900s. In the early 2000s, catastrophic erosion still ranked high as a key driver for these activities. During the first part of the 20th century, the main emphasis was on halting severe soil erosion, protecting the remaining birch woodlands and expanding the woodlands by direct seeding (Eysteinsson, 2011). Mid-century, socio-economic drivers, such as farming and the provision of wood product, became strong motivators for restoration and the emphasis shifted from being predominantly protection oriented to more production orientation with a strong focus on silviculture and large-scale revegetation to improve land for grazing and hay making (Runólfsson, 1988; Magnússon, 1997; Eysteinsson, 2011; Halldórsson *et al.*, 2011). In the 1960s and 1970s other drivers, such as the construction of hard infrastructure, moral values ("repaying the debt to the land") and aesthetical values, emerged as motivations for increased restoration effort and stimulated public involvement in land reclamation projects, analogous to the growth in number of community groups focusing on restoration in many other countries from the 1960s to the 1980s (McDonald & Williams, 2009, Stewart, 2010, Galatowitsch, 2012). The diversity of drivers for ecological restoration increased after 1990, as did the diversity of goals and approaches to restoration and soil conservation. New goals were for instance related to the establishment of the United Nations Framework Convention on Climate Change, a stronger domestic emphasis on nature conservation and recreation, and increased involvement of landowners in restoration activities. Although these new drivers, emphasizing on ecological approaches in ecosystem restoration, have been emerging in the last decades, the results from papers II, III and IV did not indicate that ecological approaches, focusing on soil conservation, were strong drivers in the current SES of rangeland management and restoration. Furthermore, public policy programmes were found to be a minor driver, which might indicate weaknesses in the policy instruments used for ecological restoration.

The SES of rangeland management

A well-structured governance system applying well-defined policies, tied to clear laws, regulations, strategies, goals and incentives and supporting strong internal and external institutional functions, has the potential to achieve and maintain social-ecological sustainability within an SES (e.g., Liu *et al.*, 2007; Basurto & Coleman, 2010). The results from Papers II, III and IV indicated that the SES of rangeland management in Iceland was lacking this institutional strength. They pointed to

key weaknesses within the administrative system, such as the lack of transparency and institutional fragmentation (e.g., Zelli, 2015), as well as the perceived lack of institutional cooperation and collaboration at higher levels.

Vertical and horizontal functions within the SES of rangeland management

Management systems should be dynamic, but too often the internal inertia and management silos within and between institutions tend to limit the functions of natural resource management systems (e.g., Liu *et al.*, 2007). The findings of paper II and IV detected several limitations of how the SES of rangeland management was functioning, both vertically and horizontally and indicated that the SES was not fully operational, most likely due to lack of internal coherency and institutional capacity. The results of paper IV for instance indicated that although more than 75% of all respondents shared the perception that while stakeholders work on rangeland restoration projects in close collaboration with the SCSI (Table 5), the knowledge application related to sustainable rangeland management and rangeland restoration within the SES in place was fragmented and not fully supporting the knowledge transfer needed, across sectors and institutions. Furthermore, knowledge on how to analyze ecological condition of rangelands in accordance with scientific findings seemed to be mainly accumulating within the environmental and the educational sectors of the system (Table 5). Paper II (Table 3 and the interviews) and paper IV (Figure 4 and the system mapping) also showed that key institutional norms, such as cooperation and transparency, were weak within the governance process and pointed out that the current institutional structure splits the agri-environmental subjects into small administrative units managed by separate agencies. That had led to the creation of functional silos, fragmented institutional arrangements, and limited cross-sectoral knowledge transfer within the SES of rangeland management.

The findings of paper IV indicated that the decision-making capacity within the SES of rangeland management was low, with more than half of respondents claiming that rangeland restoration policies were unclear and unfocused. In addition, they indicated that the content of current policies was poorly disseminated, as around 40% of all participants in the survey were not sure how to reply to questions related to rangeland´s restoration policies and the majority of all participants were uncertain as to who participates in the policy making process. That indicated a lack of good governance practices within the SES, concerning open and active stakeholder participation in natural resource management (Lockwood, *et al.*, 2010).

Papers II, III and IV indicated that the administrative changes in rangeland management in the last 30 years, such as the establishment of the FHL project (1990) and the scheme Quality Management in Sheep Farming (2003); and the transfer of competencies over environmental agencies and the agricultural University between ministries, had not improved the vertical and horizontal functions as intended. Instead, the changes might rather had deepened the functional silos detected between the

ministry that controls environmental issues and the ministry that controls agricultural issues, as well as between related institutes and organizations (Stefánsson, 2018).

The findings of papers II (Table 3), III (Table 6) and IV (Table 8) were supported by several other recent studies in Iceland, indicating that the QMS scheme and other interventions, such as the FHL programme, might not be facilitating system transition towards sustainable rangeland management as expected (Arnalds, 2019; Stefánsson, 2018; Þorláksdóttir, 2015). Their findings and the main findings of this thesis can be linked to the limitations on how the characteristics of sustainable land management/land use was defined and advocated by the agricultural sector. Since the QMS scheme was established, the concept of sustainable land use/management has appeared in agricultural regulations as a short, well-defined scientific term (Arnalds, 2019) instead of being regarded more as a framework that incorporates the various dimensions of sustainability, such as productivity, security, protection, viability and acceptability (Smyth & Dumanski, 1993). During the last years this has been highly criticized as the current definition for sustainable land management leaves out fundamental factors, such as the current ecosystem condition and thus is incapable of clarifying what can be considered unsustainable land management (Arnalds, 2019).

Rangeland management and restoration programmes

Paper II (Table 3) and III (Tables 5 & 6) showed that Icelandic sheep farmers had a positive attitude toward soil conservation and ecosystem restoration, which was in line with results from other studies (Schmidt, 2000; Berglund *et al.*, 2013). Nevertheless, this positive attitude seemed not to influence how the sheep farmers managed summer grazing on rangelands. Aside from shortening the grazing period over the past 50 years, from year-round to about 6 months during summertime with still shorter periods (2–3 months) in the highland commons, the majority of the sheep farmers still applied traditional practices of grazing rangelands (Arnalds & Barkarson, 2003). In some cases, that included also grazing on degraded or even eroded rangelands (Arnalds, 2019). Paper IV showed that although the current rangeland management and restoration programs and projects were designed to gradually increase cross-sectoral collaboration and horizontal and vertical knowledge transfer within the SES (Arnalds, 2005; Aradóttir & Halldórsson, 2011), they were not co-managed in a cross-sectoral manner, and seemed not to have significantly strengthened the respective governance process (Table 8 & 9).

Although one of the initial goals of the FHL programme was to increase sustainable land management, paper III revealed no significant differences in rangeland management practices between FHL farmers and non-FHL farmers. Nevertheless, the FHL farmers had a more positive attitude towards the SCSI, were more aware of restoration potential at their farmsteads and were more involved in various collaborative restoration activities than the non-FHL farmers. Even though the FHL programme

has been successful in facilitating increased rangeland restoration, ecological succession within the restoration areas and for building up trust between farmers and the SCSI (Berglund *et al.*, 2013), the findings of paper III (Table 6) and IV (Table 8) indicated that sustainable rangeland management practices related for instance to the grazing period and what grazing areas could be considered suitable, had not been fully adopted by the sheep farming community. The findings of paper III (Table 5 & 6) also detected knowledge gaps in the science/policy interface, that is, on how scientific results were communicated from the science community to the advisory system and from there to the farmers and back (cf. Schwilch *et al.*, 2012). Furthermore, the results of paper III indicate that a higher proportion of the FHL participants, compared with the non-FHL farmers, applied agronomic-based restoration approaches (cultivation related) rather than ecological ones (nature-based solutions) (cf. Aradottir & Hagen, 2013) and points out that this tendency towards agronomic approaches might be driven by the incentives provided by the FHL programme (Pétursdóttir, 2011). Furthermore, the flexible grazing limits for areas undergoing restoration within the FHL programme might had affected the perception of the participants and reducing their interest in applying ecosystem approaches in their restoration activities.

Organizational errors may happen when organizations fail to build up consistency between their implementation procedures and goals (Van Dyck *et al.*, 2005; Goodman *et al.*, 2011). The findings of paper III indicated the existence of organizational errors that might explain some of the identified shortcomings of the FHL programme's performance. For instance, although the programme is structured around participatory approaches, a recent study indicated that it does not fully function in a participatory way with, for instance, full stakeholder involvement in the programme management (Berglund *et al.*, 2013). Also, the relationship pattern and the level of trust between farmers and the SCSI was stronger at a regional level between a farmer and a local consultant than it was at an institutional level where it was more fragile and could easily be undermined (Berglund *et al.*, 2013) as also detected in paper II. Furthermore, the SCSI is responsible for designing and managing the FHL programme as well as for evaluating its progress (Pétursdóttir, 2011), instead of handing the evaluation out to an independent third party. The state sets no obligations with regard to how the SCSI or other public institutes should evaluate the progress of environmental programs that utilize public funds.

Paper IV revealed a gap between the sectors within the governance system for rangeland management on what they considered to be sustainable land management (Table 8). The agricultural sector and local authorities, along with the sheep farmers, favored the traditional rangeland utilization practices, while the environmental and the educational sectors supported the contemporary understandings of what practices should be considered as sustainable rangeland management, as described in paper III. Paper II, III and IV showed that although the administration of rangeland management has gradually improved in the last 30 years, the system´s institutional settings and governance practices had not adopted adaptive governance approaches, despite their obvious advantages.

Linking main outcomes to the concepts of good governance in NRM

Lockwood *et al.* (2010) provided eight principles for good governance in NRM as guidance for the establishment of multi-level good-practice governance system (Table 1). They claimed that such guidance was required in response to the novelties of governing in a multi-layered environmental context where interests are diverse, challenges are complex and coordination among private, public, and voluntary sectors is fundamental to problem-solving. The key findings of this thesis showed that the governance system under investigation failed in several cases to meet those defined principles for good governance (Table 11). Furthermore, by applying Rauschmayer´s *et al.* (2009) criteria for governance evaluation (knowledge management, social dynamics, effectiveness and legitimacy) (see framework in Figure 1) to the main outcomes of the thesis, the criteria highlights further the vertical and horizontal limitations within the existing governance system. The comparison revealed that knowledge management within the system was insufficient as there were limited cross-sectoral knowledge transfers ongoing within it and several knowledge gaps existed in the science-policy interface.

The system´s social dynamics were not fully active, for instance the decision-making capacity within the system was low, with perceived lack of institutional cooperation and collaboration and the administrative system split into functional silos and fragmented institutional arrangements.

The comparison of the thesis´s results to Rauschmayer *et al.* (2009) governance evaluation criteria supports the thesis´s findings that the SES of rangeland management was lacking institutional strength and there were key weaknesses within the administrative system, such as lack of transparency and institutional fragmentation.

Table 11. A summary of the thesis´s key findings that indicate an underlying lack of governance performance within the SES of rangeland management.

Papers no	Key findings from the papers, linked to the governance principles they adhere to	Principles for good governance	Principles for governance evaluation
II, III, IV	• The SES of rangeland management lacks institutional strength • Point to key weaknesses within the administrative system such as the lack of transparency and institutional fragmentation • Key institutional norms, such as cooperation and transparency are weak within the governance process	Legitimacy Transparency Accountability	Legitimacy
II, IV	• Current institutional structure splits the agri-environmental subjects into small administrative units, managed by separate agencies		
II, III, IV	• Perceived lack of institutional cooperation and collaboration • Low decision-making capacity within the system		
	• Functional silos, fragmented institutional arrangements	Inclusiveness	Social dynamics
IV	• The existence of organizational errors that might explain some of the identified shortcomings of the FHL´s performance (e.g., not fully participatory; farmers trust local SCSI consultants but not the SCSI and the SCSI both runs the programme and evaluate its progress)	Fairness	
II, IV			
II, III			
II, IV	• Limited cross-sectoral knowledge transfers	Integration	Knowledge management
III,	• Knowledge gaps in the science-policy interface		
IV	• Knowledge gap between the sectors what they consider to be sustainable land management	Capability	
II, III, IV	• Current administrative structure did not facilitate the expected attitude changes within the agricultural sector and among local authorities, or behavioral changes among sheep farmers towards improved rangeland management, in line with current agri-environmental policy targets		
II, III, IV,	• The QMS scheme and other interventions, such as the FHL programme might not be facilitating system transition towards sustainable RM		
II, IV	• Several limitations of how the SES was functioning, both vertically and horizontally – indicate the system was not fully operational, most likely due to lack of internal coherency and institutional capacity	Adaptability	Effectiveness
II, III, IV	• Administrative changes in RM in the last 30 years have not improved the vertical and horizontal functions as intended. The changes might rather have deepened the functional silos detected within the system		
II, III	• The system´s institutional settings and governance practices have not adopted adaptive governance approaches		

The findings are listed by the number of the paper they are described in and linked to the principles for good governance (Lockwood *et al.*, 2010) and the principles for governance evaluation (Rauschmayer *et al.*, 2009).

The key findings of Paper II (Table 4), III (Table 6) and IV (Table 9) highlight that current administrative structure of rangeland management has not facilitated the expected attitude changes within the agricultural sector and among local authorities, or behavioral changes among sheep farmers towards improved rangeland management (and restoration), in line with current agricultural and environmental policy targets.

Conclusions

In this thesis, mixed quantitative and qualitative methods, that is, a survey with quantitative questions, secondary data analysis and semi-structured interviews, were applied to do a social-ecological system analysis (SES) of rangeland management and restoration in Iceland, to assess if the expected long-term progress of identified policy goals and related programs and projects has been achieved. The value of doing a research that applies both quantitative and qualitative methods is demonstrated by the realization that it would have been impossible to collect data and process them only with a single analytical method without risking losing critical information on the system´s components. That includes the historical background information, secondary data on the ecological condition of the rangelands and the deep insight into the system achieved by interviewing selected stakeholders and asking for stakeholders´ perceptions or opinions on issues related to rangeland management in general. The robustness of this research also lies in the fact that the whole population of those who were identified as having a stake in rangeland management was involved in the research. Thus, the rate of participation enables comparison across the whole population, not to a sample from it.

The combined results gave a thorough insight into the SES of rangeland management in Iceland and provided strong signals on the overall progress of rangeland management projects and programs as well as revealing several governance or administrative limitations and blockages within the system. The social-ecological system approach, including the SES framework, provided helpful criteria for unpacking the case under analysis, in particular to reveal the structure and functions of the different components of the system and to visualize the connections to other factors, such as the respective social, economic and political setting and related ecosystems.

To strengthen good governance practices and aim for sustainability within the social-ecological system of rangeland management, the following recommendations are provided:

- **Redesign the current structure of the agricultural administration and include the Ministry for Environment and Natural Resources directly into the decision-making process**. The fragmented structure of agricultural administration, the exclusion of the MENR and its agencies from the agricultural land use policy process, and the lack of direct access of the farmers' business interest organizations (FA) to the policy decision making process within the MII needs to be addressed.

- **Create a formal transdisciplinary platform for rangeland governance**. The lack of a formal platform for participatory forms of rangeland governance leaves few opportunities for more active participation and information sharing between and within the stakeholder groups as well as between them and other institutions operating within the system of rangeland governance.

- **Improve the legal definition for the term "sustainable land management".** The legal definition for sustainable land management needs to be revised and made more robust in the context of ecosystem condition and ecosystem capacity. What is considered unsustainable land management also needs to be clarified.

- **Incorporate adaptive governance and adaptive management into the SES of rangeland management**. The structure of large-scale rangeland management and restoration programs needs to be systematically monitored to identify potential organizational errors that might be restricting the expected performance and the information collected, used to strengthen the organizational setting.

Future work

This thesis provides a baseline for the design and implementation of a robust natural resource governance in Iceland with sustainable management as a priority objective. Furthermore, it would be highly beneficiary to use the analysis conducted here to do research focusing on performing a socio-economic evaluation on the current rangeland management system and develop several future rangeland management scenarios as comparisons to the current system. The results could then be used to do a cost-benefit analysis for all the options. Finally, it would be possible to come up with a policy recommendation on what rangeland management system would be the most beneficiary for Iceland, in the social-ecological and economic context.

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