Title: Institutions and adaptation processes: A social-ecological system approach for the study of adaptation to climate change

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ABSTRACT

As the international community continues to engage in protracted negotiations over how to implement reductions in greenhouse gas emissions, the likelihood that society will face disturbances from extreme events and prolonged warming has increased. There is therefore a need to better understand the process by which adaptation occurs and in particular how the social, ecological and institutional attributes of a system affect important choices along a pathway from environmental disturbance to adaptive outcome. This paper therefore links institutional analysis and the related social-ecological systems framework to the literature on adaptation and robustness to develop an evaluative framework for the study of adaptive processes. This framework allows scholars to investigate how government policies and other attributes of the social-ecological environment affect the ability of actors to resolve a series of adaptation problems they face.

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1.0 INTRODUCTION

As the international community continues to engage in protracted negotiations over how to implement reductions in greenhouse gas emissions, the likelihood that society will face disturbances from extreme events and prolonged warming have increased (Christensen et al. 2007; Coumou and Rahmstorf 2012). Whereas global attention remains focused on strategies for mitigation to alleviate the threat (Goulder and Parry 2008; Spash 2010; Ostrom 2010; Soares-Filho et al. 2010; Thompson et al. 2011, IPCC 2013); there has been a definitive rise in the salience and study of adaptation to environmental change. These efforts have culminated in the identification of a wide range of factors that generally increase prospects for successful adaptation (Smit and Pilifosova 2003; Adger et al. 2007; IPCC 2012). However, these comprehensive reports also reveal that successful adaptation is complex, and that the performance of adaptive strategies varies considerably across different types of disturbances (Carlson and Doyle 2002; Janssen et al. 2007; Schoon and Cox 2012), the context and scale at which they operate (Adger et al. 2005; Smit and Wandel 2006), and the ways in which adaptive performance is assessed (Smit and Wandel 2006). Thus, like much of the literature on environmental governance, the study of adaptation and adaptive capacity has led to a complex systems approach and the general conclusion that successful adaptation depends upon the fit between adaptive governance systems and the social-ecological system (SES) in which they operate.

Adaptive capacity refers to the "capability of a system to maintain essential attributes of its self-organizing structure, function, and feedback mechanisms" in response to disturbance (Armitage 2007). The capacity to adapt in turn depends upon a set of system properties that allow individuals or communities to adjust or recover from exogenous or endogenous perturbations in social or environmental conditions. The study of adaptation therefore, is concerned about the processes by which individuals and groups select and implement adaptive strategies, but also about how those choices are affected by the resources, information, and knowledge of the participants, and relations with other formal and informal political processes (Adger et al 2005; Keskitalo et al 2011). It is closely related to the ecological concept of resilience that emphasizes the persistence of systems and their constitutive relationships in the context of change and disturbance (Holling 1973; Biggs et al. 2012; Folke et al. 2010); and the concept of robustness that emphasizes the maintenance of one or more system characteristic despite internal or external disturbance (Carlson and Doyle 2002; Anderies 2006; Janssen et al. 2007). Yet adaptive capacity is also somewhat different from either resilience or robustness in that it specifically emphasizes choice and human agency and the attributes of choice environments that allow groups and individuals to foresee or respond to ecological consequences of social actions and to navigate through change, risk and perturbations without getting trapped in inefficient and unsustainable patterns of interaction, creating vulnerabilities. Thus far most attempts to integrate knowledge concerning adaptation have had to confront severe analytical and evaluative challenges and have therefore settle for the identification of highly generalized characteristics associated with successful adaptation. Nonetheless the speed at which these characteristics have been identified is impressive and the literature has made considerable strides towards a general theory of adaptive capacity and adaptive governance.

The paper is structured in the following way. Section one continues by discussing adaptation and adaptive capacity in the context of climate change. Section two introduces the SES framework while section three adapts the SES framework to study adaptive processes; which is then applied to a case study in section four. Section five then concludes the paper by discussing important issues concerning the study of adaptive processes.

1.1 Determinants of Adaptive Capacity

Contemporary theories of adaptive capacity suggest that successful adaptation depends upon a wide range of social, institutional and economic factors as outlined in table 1 below. In general these include the human (i.e. knowledge, skills, social capital), physical and financial capital that groups possess; and the ways in which institutions and networks connect these resources to affected groups to encourage the choice and implementation of successful adaptive strategies (Smit and Wandel 2006; Smit and Pilifosova 2001; Smit and Skinner 2002; Tompkins and Adger 2004) Although these general factors appear to increase prospects for successful adaptation across a large population of cases, the literature also indicates that their effects vary across social-ecological contexts (Smit and Wandel 2006). In other words, the performance of adaptive strategies and governance systems depend upon their fit with the attributes of the complex and dynamic social-ecological environment in which they operate (Acheson and Wilson 1996; Holling and Meffe 1996, Hovelsrud et. al 2010).

Table 1: Determinants of Adaptive Capacity (Adapted from Lemos et al. 2013 and Smit et al. 2001)

Determinants of adaptive capacity	Description
Human Capital	Attributes of individuals and groups facing or responding to environmental disturbance (i.e. scientific and traditional knowledge, education, labor force, specialized skills)
Information and communication	Attributes of the dissemination and quality of information sharing among and between individuals/groups (i.e. communication networks, ease of access, learning)
Technology and infrastructure	Attributes of the physical capital of a system facing disturbance (i.e. roads, water delivery, sewage, energy facilities, monitoring technologies)
Organization and social capital	Attributes of the connections between individuals and organizations and their ability to mobilize groups and/or resources towards collective aims. (i.e. state-civil society relations, trust networks)
Institutions and political capital	Attributes of political systems, policies, formal and informal rules and leaders that effect collective action and decision-making
Wealth and financial capital	Financial attributes of individuals and groups facing environmental disturbance (i.e. wealth, distribution of wealth, insurance)

In addition to these anthropogenic determinants of adaptive capacity, the state of the ecosystems is also crucial for overall adaptive capacity. The TEBB project (The Economics of Ecosystems and Biodiversity – a follow up to the Millennium Ecosystem Assessment), concluded that human activity had a clear and increasing negative effect on the planet's biodiversity and ecosystems. It also concluded that the robustness of ecosystems themselves – and their capacity to adapt to changes – has been reduced. Approximately 15 of the Earth's 24 defined ecosystems were found to be in decline (TEBB 2010a, 2010b). Although problematic in some respects, decline and knowledge of said decline may also represent an opportunity for transformation. SESs might become highly sensitive to perturbation – and consequently release nutrients and opportunities for reorganization and new ways of exploitation (Gunderson and Holling 2002). New crops, genetic livestock material, property rights incentive systems can spur such transformations. Innovation, institutional entrepreneurship and transforming approaches to management and governance of such systems can accelerate the exhaustion of resources – or it can increase the resilience of the social-ecological system, it all depends on the knowledge base and on the time horizon, (Westley et al 2013).

Ecological systems often contain positive feedbacks, tipping points, creative destruction and unwanted surprises. Social systems, on the other hand, are often characterized by institutional stability, path dependency, "social traps" and political inertia (North 1990). The underlying complexity and potential incompatibility among subsystems poses grave analytical challenges (Agrawal 2003; Young et al. 2006) and is incompatible with most existing scientific models and policy frameworks that seek to soften complexity in pursuit of optimal solutions or more simple policy panaceas (Ostrom 2005; Ostrom et al. 2007). This paper therefore advances an argument that inherently complex systems require robust analytical frameworks that can manage or cope with this complexity, while allowing for systematic inquiry of its component parts such that scholars and practitioners can cumulatively piece together knowledge concerning the relative merits and consequences of different policy alternatives or combinations thereof. A framework for complex systems also draws attention to the uncertain, tentative or context-specific nature of research findings, and views policy change or reform as an informed experiment based on some expectation concerning potential outcomes.

2.0 ANALYTICAL FRAMEWORKS FOR THE STUDY OF SOCIAL-ECOLOGICAL SYSTEMS

Environmental policy scholars are confronted by a large assortment of frameworks, theories and models that may be used to describe, analyze and diagnose social-ecological systems. Binder et al. (2013) identify and evaluate ten established frameworks for the study of SES's, all the while acknowledging that this is far from an exhaustive list. These ten frameworks vary along several dimensions, including the relative emphasis they assign to the social or ecological components of a system, the ways in which the components are linked, the topics or outcomes they are designed to study, and the specific attributes of the system that are viewed as the principal causal drivers of social-ecological outcomes (Binder et al. 2013). At times the heterodoxy of analytical tools

may be seen as a great enabler of research by equipping scholars with a diversity of approaches to capture the complex features of SESs, or draw attention to particular aspects of environmental problems. However, it also poses immense challenges for scholars seeking to piece together knowledge when they lack a common language, and an understanding of each others methods and causal assumptions (Agrawal and Ostrom 2006). Given the urgent need for a social-ecological theory of successful environmental governance and the development of policies to respond to mounting environmental problems it is unclear whether the heterodoxy as a whole benefits, or hinders these efforts. The SES framework introduced by Ostrom (2007; 2009) presumes the latter and aims to provide a common interdisciplinary tool for the study of complex SESs.

2.1 The SES Framework

The SES framework presented in Table 1 is the culmination of many years of research that collectively moved the study of environmental governance from the pursuit of institutional panaceas such as external regulation (Gordon 1954; Hardin 1968) to the recognition that self-governance is possible (Johannes 1978; Ostrom 1990; Wade 1994), and finally to the general hypothesis that successful environmental governance depends upon the fit between institutions and the SES (Ostrom 2009). Whereas the first two phases could be completed without a complicated orienting framework by using either highly restrictive behavioral models, or by documenting empirical observations of successful community governance; the latter implies a complex set of interactions among institutions and conditions and effectively begs for a framework to piece together this complexity. The SES framework is explicitly designed to cope with this complexity by adopting a nested partially decomposable structure that seeks to build knowledge cumulatively by synthesizing research across method, level of inquiry and sets of independent variables. For example Epstein et al. (ICCAT in review) apply a modified SES framework to find that the long-held hypothesis that the presence of resource storage enhances prospects for sustainability does not transfer from the canal irrigation systems in which it was developed (Schlager et al. 1994) to Atlantic Bluefin Tuna storage facilities or ranches. While the paper is unable to determine the exact cause of this difference, it draws upon the framework to identify several differences across canal irrigation systems and the Bluefin fishery that await future empirical research. Knowledge is thus pieced together by exploring the effects of SES attributes in different SES environments to understand when particular attributes increase prospects for positive social-ecological outcomes.

Table 2: The social-ecological systems framework as adapted in Epstein et al. (2013) based on Ostrom (2009)

Ecological Rules (*ER*) *ER1 Physical rules *ER2 Chemical rules *ER3 Biological rules		
	Social, Economic, and Political Settings (S) **S1– Economic development. S2– Demographic trends. S3– Political stability.** **S4– Other governance systems. S5– Markets. S6– Media organizations. S7– Technology.**	
	Resource Systems (RS)	**Governance Systems (GS)**
	RS1– Sector (e.g., water, forests, pasture, fish) **RS2– Clarity of system boundaries** **RS3– Size of resource system** **RS4– Human-constructed facilities** **RS5– Productivity of system** **RS6– Equilibrium properties** **RS7– Predictability of system dynamics** **RS8– Storage characteristics** **RS9– Location**	**GS1– Government organizations** **GS2– Nongovernment organizations** **GS3– Network structure** **GS4– Property-rights systems** **GS5– Operational-choice rules** **GS6– Collective-choice rules** **GS7– Constitutional-choice rules** **GS8– Monitoring and sanctioning rules**
	Resource Units (RU)	**Actors (A)**
	RU1– Resource unit mobility **RU2– Growth or replacement rate** **RU3– Interaction among resource units** **RU4– Economic value** **RU5– Number of units** **RU6– Distinctive characteristics** **RU7– Spatial and temporal distribution**	**A1– Number of relevant actors** **A2– Socioeconomic attributes** **A3– History or past experiences** **A4– Location** **A5– Leadership/entrepreneurship** **A6– Norms (trust-reciprocity)/social capital** **A7– Knowledge of SES/mental models** **A8– Importance of resource (dependence)** **A9– Technologies available**
	Action Situations: Interactions (I) ⟶ Outcomes (O)	
	Activities and Processes:	**Outcome Criteria:**
	I1– Harvesting **I2– Information sharing** **I3– Deliberation processes** **I4– Conflicts** **I5– Investment activities** **I6– Lobbying activities** **I7– Self-organizing activities** **I8– Networking activities** **I9– Monitoring activities** **I10– Evaluative activities**	**O1– Social performance measures (e.g., efficiency, equity, accountability, sustainability)** **O2– Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)** **O3– Externalities to other SESs**
	Related Ecosystems (ECO) **ECO1– Climate patterns. ECO2– Pollution patterns. ECO3– Flows into and out of focal SES.**	

There is, however, a second and crucially important aspect of the SES framework that is explicitly designed to allows scholars to evaluate the choices of individuals and groups, and the attributes of the social, ecological and institutional environment that affect those choices. The action situation, presented in figure 1 below occupies a central position in the SES framework

and was retained from the related institutional analysis and development (IAD) framework (Ostrom 2005). The action situation is a general model of institutionally structured arenas of interdependent choice (McGinnis 2011a) where aggregations of individual choices given payoffs that are mediated by the institutional and broader social-ecological setting drive social-ecological outcomes (Ostrom 2009). For example, Ostrom et al. (1994) and several other studies (Cárdenas and Ostrom 2004; Janssen 2010) demonstrate how institutions that allow users to communicate with and/or sanction one another can substantially alter individual choices and outcomes in experimental environments by changing the incentives that uses face when making those choices. Attributes of the social-ecological environment can play a similar role, as characteristics such as the size of a resource system, and overlap with resource location impact the likelihood that an individual will be detected violating rules, and thereby alter the incentives users face when choosing to comply with or violate resource management rules (Wade 1994). The action situation has thus served an important role in the development of a theory of sustainable environmental governance and has enabled institutional analysis scholars to synthesize knowledge across multiple methods of inquiry (Poteete et al. 2010). However, the overwhelming focus on single action situations neglects the multiplicity and diversity of choice situations that affect the sustainability of SES's (McGinnis 2011b)

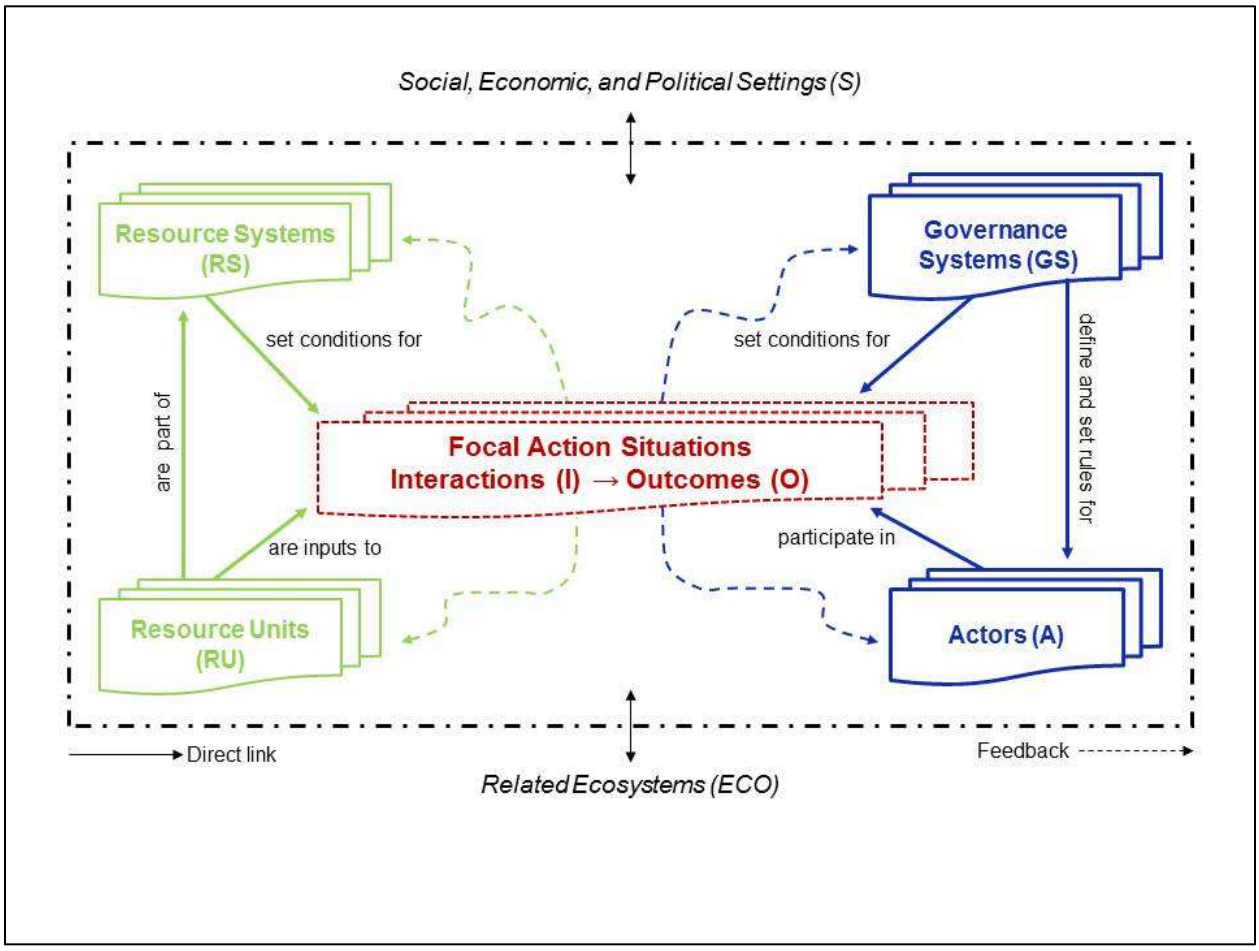

Figure 1: The action situation at the core of the SES Framework as presented in McGinnis and Ostrom (forthcoming)

The sustainability of social-ecological systems is ultimately the result of a lengthy process of trial-and-error learning wherein individuals and groups confront a diverse assortment of social and ecological problems and devise an equally diverse set of institutional solutions to manage those problems given their unique circumstances (Ostrom 2013). While studies of individual action situations may illuminate institutions that increase prospects for desirable outcomes, it does not explain the process by which those institutions were developed and/or are maintained to produce that outcome. In other words, studies of single action situations may be able to identify "what matters", but be unable to explain whether the institutional attributes that matter are transferable to other social-ecological settings, or whether actors are likely to invest in costly operational activities such as monitoring, sanctioning and conflict resolution. As an example, McGinnis (2011b) describes how the general sustainability of Maine's lobster fisheries depended upon a series of action situations where users and other stakeholders developed rules, resolved conflicts, and monitored resource conditions and user behavior that jointly contributed to maintain harvesting levels within acceptable limits. The essential point is that to understand the sustainability of Maine's lobster fishery, one must consider both how monitoring, rules and conflict resolution affect harvesting levels, but also how groups were able to choose biologically-meaningful rules, and develop a set of supportive formal and informal monitoring and sanctioning processes that promoted compliance with those rules (Acheson 1997). In effect this approach argues that in order to understand outcomes in SESs, we must evaluate the process by which those outcomes arise.

3.0 A FRAMEWORK FOR THE STUDY OF ADAPTIVE PROCESSES

In this section we demonstrate how the SES framework can be adapted for a choice-oriented theory of adaptation by focusing on the choices and activities that individuals' and groups make and undertake and collectively affect their ability to adapt to disturbance. We do so by drawing upon an adaptive process model presented in Moser and Ekstrom (2010) that identified factors that act as barriers at multiple phases of the adaptation process. They identify three main phases in adaptation processes; understanding, planning and managing which are further broken down into sub-phases where choices are made and/or activities are undertaken in light of those choices. For example, they suggest that some groups may fail to adapt simply because they do not identify a disturbance as a salient concern due to their inability to separate environmental change from background noise; while others may fail to implement a chosen strategy to respond to environmental disturbance because of a lack of financial resources, or clear guidance as to how they should proceed. Although their model and accompanying framework can be used for the diagnosis of potential barriers that may undermine adaptive capacity in specific cases, it does not provide insights into the broader situational attributes that alongside with those barriers affect adaptive choices in each of these phases, nor does it provide a systematic way in which to evaluate how attributes of the SES give rise to particular choices and adaptive outcomes.

Figure 3 therefore seeks to resolve these issues by using the SES framework and the concept of linked action situation to evaluate how attributes of a SES affect six key phases of the adaptive process. These include i) the identification, classification and recognition of problems, (ii) the search and identification of potential adaptive strategies, (iii) the ways in which those strategies are evaluated (iv) the choice of adaptive strategy from amongst the set of identified alternatives, (v) the implementation of chosen strategies and finally (iv) the extent to which the chosen

strategy or strategies as implemented fit or resolve the problems generated by a disturbance. The disturbance, itself, is viewed as an exogenous input into the system that can classified in terms of its defining characteristics as well as measures of its duration, intensity, frequency, and severity (Schoon and Cox 2011). Although the disturbance is classified as an exogenous input it may arise from processes occurring in the focal SES. But since we are interested in how and whether actors adapt, we do not consider whether changes to these processes could mitigate the effects of that disturbance

The individual phases, themselves can be modelled or conceived as situations wherein the attributes of a system interact to generate outputs or outcomes as a result of rule-governed processes (Anderies 2002; Epstein et al. 2013). Generally speaking the fit between adaptive strategies are more likely to be driven by ecological or technical rules. For instance, the performance of fisheries stock enhancement strategies via habitat restoration can be seen as the output of a rule-governed ecological process that links the characteristics of restored habitats to levels of biological recruitment or population growth (Feunteun 2002; Bell et al. 2006). Meanwhile, the remaining phases involve social processes that can be understood as institutionally mediated action situations (see McGinnis 2011a; Ostrom 2005) where actors make choices that are mediated by institutions (generally rules and social norms) and other attributes of the social-ecological environment. In other words, the interactions and choices of actors are governed, but not determined, by the policies, social rules and customs of the participants in a given action situation. The principal advantage of conceptualizing these processes as rule-governed interactions is that it enhances the ability of scholars to analyze the inherently complex system using multiple methods of inquiry (Poteete et al. 2010) and also allows us to draw upon the wealth of knowledge that has been developed using the same general approach to study successful common-property governance.

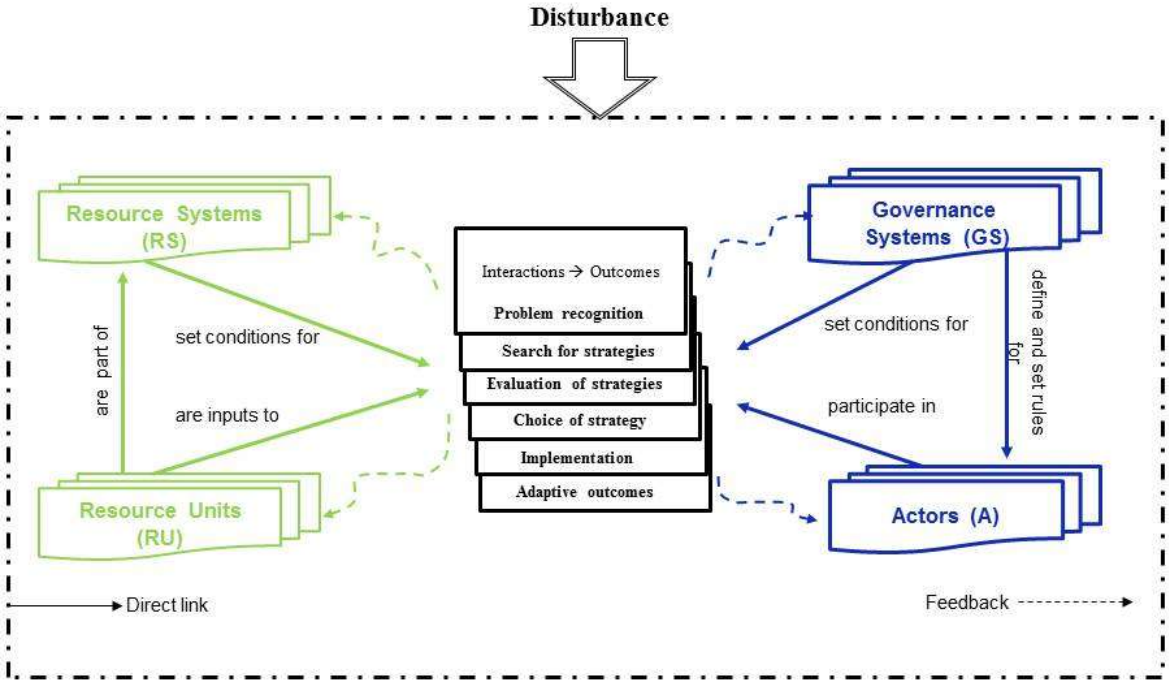

Figure 2: A problem-oriented framework for the study of adaptive capacity

Section 3 continues by introduce each of the six general types of interactions evaluated in this framework, as well as the exogenous disturbance. The temporal sequencing presented in this framework does not necessarily capture individual or collective adaptive processes in all situations where simultaneous identification, evaluation and choices are often likely (Jones 1999; Moser and Ekstrom 2010), and disturbances may arise at various stages of this process. Instead the adoption of a general analytical framework allows for the evaluation of adaption across SES, and aids the development of a theory of adaptation.

3.1 Disturbances

Disturbances are changes or fluctuations in one or more system components or their interactions that effect social, ecological or social-ecological processes in a SES (Schoon and Cox 2011) and are often referred to as exposure-sensitivities in the adaptation literature (Turner et al. 2003; Smit et al. 2010). The framework considers disturbances as exogenous inputs into a SES. Although many disturbances may arise as a direct result of interactions that occur within the focal SES (i.e. overharvesting, emission of pollutants), the focus on adaptation rather than mitigation means that the framework is less concerned with the specific origins of the disturbance and more concerned with how people respond to that disturbance.

Schoon and Cox (2011) identify four general classes of disturbance which include changes in (i) material and energy flows between SESs, (ii) the value of system parameters within a SES, (iii) linkages or network structures among the components of an SES, and finally (iv) linkages or level of connectivity between SESs or nested systems. For instance the transport of nutrients from terrestrial to aquatic systems would be seen as a flow disturbance, while increased average temperatures reflect changes in the value of a system parameter (Schoon and Cox 2011). Disturbances also vary in terms of their intensity, duration, severity and frequency, and may emerge from both social and ecological processes. Ecological disturbances include such things as droughts, floods, climate change, invasive species, and pollution while social disturbances arise from changes in market prices, demand, governance systems, and the number or types of individuals and groups in a SES. Most disturbances in the context of climate change arise as a direct or indirect result of changing climate patterns (ECO1) and can be evaluated in terms of the type of disturbance as outlined above or with respect to measures of the magnitude and frequency of the disturbance. The fit between the attributes of a disturbance, implemented adaptive strategies, and the attributes of the surrounding social-ecological environment ultimately determines the individual and collective adaptive outcomes that are observed (Young 2002).

3.2 Problem recognition

Conscious and deliberate adaptive processes ultimately begin with some level of recognition that a disturbance has, or is likely to take place. If actors possessed complete information about the social-ecological environment, and the cognitive ability to process that information to assign probabilities over outcomes then problem recognition would be a more-or-less straightforward process. However, human beings neither possess sufficient understandings of complex SES's

(Holling and Meffe 1996; Armitage et al. 2008b), nor do they process that information in an objectively rational way (Kahneman and Tversky 1979; Simon 1997; Jones 1999). Instead human beings are intendedly rational and rely upon sets of heuristics, or 'rules of thumb' to make inferences about the world around them. Although in many cases these heuristics are advantageous by allowing people to make decisions in otherwise complex situations (Gigerenzer and Goldstein 1996), they also yield systematic biases that are potentially problematic in a changing world. For instance human beings tend to evaluate stimuli in ways that confirms their own preconceptions (Nickerson 1998), and even when perceptions and beliefs change, they tend to be conservative incremental adjustments that may not capture the full extent of the social-ecological disturbance (Hilbert 2012).

Successful adaptation to disturbance then depends in part on the ability of actors to detect signals of a (potential) disturbance, identify and categorize potential threats, and then decide that the disturbance constitutes a problem meriting additional attention (Moser and Ekstrom 2010; Wolf et al. 2010). Therefore, problem recognition processes can be evaluated along several salient dimensions including the temporal sequencing of disturbance and recognition of problems, the ways in which problems are defined (and accuracy thereof), and the overall efficiency of the process. The time dimension, and in particular whether problems are identified prior to or after the onset of a disturbance, may be crucially important as the set of potential adaptive strategies is likely to be more limited in a reactive, rather than proactive adaptive process (Smit and Pilfisova 2001; Bierbaum et al. 2013). On the other hand, groups that devise proactive adaptive strategies to recurrent and relatively mild disturbances may actually increase their vulnerability to disturbances that are less common (Anderies 2006). In general, prospects for successful problem recognition appear to increase with the availability of resource monitoring technologies (A9) and network structures (GS3) that link scientific (A7a) and local knowledge (A7b) of the SES (Armitage et al. 2008), the predictability of system dynamics (RS7), and the availability of indicators of variation in system parameters (RS7a) (Basurto and Ostrom 2009).

3.3 Search for adaptive strategies

Once problems are recognized, defined, categorized and deemed worthy of a response; actors may organize in a variety of formal and informal venues to consider alternative adaptive strategies. In effect the search for adaptive strategies provides the set of alternatives from which actors choose how to respond to a particular disturbance. Theoretical perspectives concerning the search for alternatives vary, but once again models of bounded rationality suggest that any search is likely to be incomplete relative to the full suite of potential adaptive strategies. Bounded rationality, for instance, suggests a close coupling between searches and choices, and that searches will be truncated once individuals identify a strategy that satisfies some level of aspiration (Simon 1997). Search in group settings such as formal governance systems and organizations is slightly different because they can leverage design features such as decentralization and delegation to allow for parallel processing of information (Jones 1999). When environmental changes are perceived to be small, these sub-groups may develop rapid responses in the form of pre-existing solutions or standard operating procedures rather than engage in a protracted search. Large-scale and highly visible changes, on the other hand, may shift attention towards a more comprehensive search process (Jones 2003). Nonetheless, when actors face complex problems they often focus their search on strategies adopted by groups

facing similar problems (Dimaggio and Powell 1983; Berry and Berry 2007); and may therefore overlook strategies that would better fit their own unique social-ecological context.

The performance of search processes can be evaluated by considering the number, diversity and types of identified strategies, as well as the overall efficiency of the process. Some potentially influential attributes include the number (A1) and diversity (A2) of actors involved in search processes, as well as leadership (A5), and network structure (GS3) among actor groups (Moser and Ekstrom 2010). For example in a study of adaptive strategies in Canadian agriculture, it was found that scientific experts tend to draw upon their specific knowledge to offer technological solutions, while governments leverage financial resources to offer subsidies or crop insurance programs and individual farmers consider potential alterations to production practices (Smit and Skinner 2002). However, not all farmers may be aware of the vast array of potential adaptation alternatives unless accompanied by formal or informal mechanisms that link information about about adaptive strategies between and within groups. Interactions among attributes of an SES may be especially important for search processes, as different combination present different challenges. Small groups or individuals may lack the resources to identify a wide range of potential strategies, while large groups may identify a wide range and diversity of adaptive strategies but lack the time and resources to bring these together unless combined with leaders or nested governance structures.

3.4 Evaluation of adaptive strategies

Evaluation, in this context refers to the process and content by which identified strategies are considered and ranked against other identified alternatives, including the status quo. Evaluative processes may include formal or informal analysis of costs and benefits (Stern 2007; Basurto and Ostrom 2009; Gintis 2009); sophisticated mathematical models (Matthews et al. 1997) or simply successive individual comparisons to the status quo (Samuelson and Zeckhauser 1988), among other formal and informal processes. The content of evaluation is equally important and refers to the criteria, desired outcomes or goals that actors set and then use to evaluate alternatives. Both the process and content of evaluation play a major role in the choice of adaptive strategy, and can at times lead actors towards the selection of inferior alternatives. For instance, cost-benefit analysis requires that economic values, discount rates and probabilities be assigned to each alternative. However in the context of the potentially disastrous effects a climate change a precautionary approach may be more appropriate (Tol 2003). Individual evaluations may face similar problems as beliefs and uncertainty concerning the likelihood and timing of a disturbance may lead individuals to considerably lower valuations for adaptive alternatives when compared to the status quo. Finally by evaluating on the basis of contemporary social values groups may fail to consider the potential need to fundamentally alter their evaluative templates towards more sustainable social values (Armitage et al. 2008; Adger et al. 2009).

An effective evaluation process in the context of climate change adaptation would be expected to evaluate alternatives on the basis of the goals and values of affected parties, and focus on long-term costs and benefits. The ways in which actors evaluate and incorporate risk may be equally important as limited risk tolerance may lead to the selection of strategies that are unable to cope with unexpected variability. In other words, actors may need to adopt a precautionary approach,

rather than a strict cost-benefit analysis of alternatives. Some specific dimensions include the classic institutionalist criteria such as the efficiency, effectiveness, equity and legitimacy of the process (Ostrom 2007), the economic factors and social values included in evaluations, and the ways in which actors consider risk and uncertainty in their evaluations. Although far from a complete account, successful evaluative processes are more likely when they leverage multiple types of knowledge systems (A7) in a networked multi-level governance system (GS3) that gives priority (GS6) to the social values, interests (A6) and socioeconomic contexts (A2) of affected parties (Dow et al. 2006; Armitage 2007b). Adger et al. (2009) for instance argue that a failure to account for the values that cultures assign to landscapes and places in cost-benefit studies leads to a systematic undervaluation of adaptation and may over time lead to real cultural losses.

3.5 Choice of adaptive strategy

The choice of adaptive strategy or strategies refers to the process by which actors select from among a set of identified and evaluated alternatives. These choices take place in collective-choice settings and produce the operational rules that are ostensibly chosen to improve prospects for successful adaptation. Settings may be as formal as international-level treaty negotiations and national parliaments, or as informal as community meetings and even uncoordinated individual decision-making. General models of institutional change predict that individuals will select a strategy that is perceived to generate the greatest perceived benefit relative to the combination of benefit flows from current strategies, and costs associated with institutional change and implementation (Basurto and Ostrom 2009). However, in certain settings the logic of collective action may lead some groups to select socially inferior strategies as a result of the distribution of individual benefits and costs (Olson 1965; Hardin 1982). Moreover, even though groups may be *willing* to pay for a particular adaptive strategy, they may lack the *ability* to pay and therefore pursue lower ranked alternatives (Hovelsrud et al. 2010).

A successful choice process would be expected to result in the selection of preferred adaptive strategies that represent the values and interests of affected parties via an efficient, fair and equitable process. These processes can therefore be analyzed by considering whether the attributes of choice processes facilitate or inhibit the selection of preferred adaptive strategies, satisfy concerns about democratic rights and individual liberties, and whether they provide adequate representation of majority and minority values and interests. There are of course potential tradeoffs among these evaluative dimensions. Engle and Lemos (2010), for instance, find that the adaptive capacity of river basin governance in Brazil is positively associated with user participation and representation, but negatively associated with the overall equity of that process. Similarly, in one of these river basins the successful response to a drought was facilitated by the formation of a small technical (and less democratically accountable) group that nonetheless was able to make the rapid decisions necessary to respond to changing conditions. Therefore attributes of successful choice processes are likely to vary immensely across context, and the ways in which success is evaluated. Nonetheless, we would expect that groups that possess greater economic resources (A2) and social capital (A6) or networked governance structures (GS3) that connect resources and knowledge across levels will face fewer constraints in the selection of preferred strategies (Armitage 2007)

3.5 Implementation

Implementation refers to operational activities that are undertaken by actors to generate desired outcomes in accordance with a policy, decision, or choice (Anderson 2006). Operational activities may encompass a diverse assortment of governance processes ranging from the collection and dissemination of information, construction or maintenance of infrastructure, monitoring compliance with rules, and conflict resolution. Implementation is often overlooked in policy analysis which focuses on the effects of policy choices on outcomes. However, many years of research clearly indicate that studies which neglect implementation risk overlooking a critical chapter that may ultimately explain the performance of a particular policy or choice (Pressman and Wildavsky 1973; Sabatier and Mazmanian 1980; Lin 2000; Hoffman 2009; McGinley and Cubbage 2012). Government agencies, for instance, often adopt policies but then fail to provide the financial resources, knowledge, political will, or legislative support to take actions in support of that policy (Randall 2004; Keane et al. 2008; Hansen 2011). Implementation thus serves an important mediating role between the choices that actors make and adaptive outcomes.

The central question to evaluate implementation is whether the actions taken by actors correspond to, or are in support of a chosen adaptive strategy; and whether those actions are effective, efficient and fair. Barriers to adaptation are particularly salient in the implementation phase where actors may need to devote considerable financial and human resources, potentially over a long period of time, to ensure that a strategy is implemented properly. For example, Armitage (2005) describes how government actors in Nunavut's narwhal management program took great strides to recognize aboriginal rights and decision-making authority, but then failed to provide adequate support for important operational activities. Although as of yet the absence of these resources has not had a significant impact on performance, Armitage (2005) suggests that it may have substantial effects as these groups confront changing social, economic and ecological conditions. In general, prospects for successful implementation of an adaptive strategy would be expected to increase with the socioeconomic status of actors (A2), clearly specified adaptive strategies (GS3), technical knowledge (A7), and leadership (A5) that encourages learning throughout the implementation process (Pressman and Wildavsky 1973; Armitage et al. 2008b)

3.6 Adaptive outcomes

Finally, once actors have identified a problem, searched for, evaluated, selected and implemented an adaptive strategy, the final remaining question is whether this process has resolved the problem it was meant to address, and contributed to successful adaptive outcomes (Young 2008; Cox 2012). Successful adaptation can be defined and measured in a variety of ways that generally compare the social and economic well-being of actors and the production of ecological goods and services prior to and after the onset of disturbance. Although individual studies may use only one or a small number of indicators of success, it is important to note that these indicators may themselves form a variety of synergistic and trade-off relationships with one another, or vary with respect to the ways in which actor groups are defined and the temporal and spatial scale of analysis (Adger et al. 2005). Success, quite simply is a highly contestable term that should give caution to researchers and practitioners, but nonetheless serves an important analytical roles for the development of a theory of adaptation.

The likelihood that an implemented adaptive strategy contributes to a successful outcome would be expected to depend on two sets of attributes. The first of which is the extent to which the selected adaptive strategy (GS3) fits the problems generated by a disturbance. A tentative evaluation of fit can be made insofar as a strategy is associated with one or more measures of success. However, stronger arguments concerning fit can be made when scholars demonstrate the existence of a causal mechanism that links an implemented strategy to the successful result (Hedström and Ylikoski 2010), or alternatively draws upon empirical counterfactuals in a comparative or matching design (Shadish et al. 2002; Rubin 2005). For instance, Shepherd et al. (2006) used a pre-post design to demonstrate changes in water use as a result of the introduction of a water pricing strategy among residential and agricultural water users in the Okanagan region of British Columbia. However, given the significant per capita reductions observed among residential users and the more modest results in agricultural settings the authors suggest that the chosen water pricing strategy was better attuned to the social-ecological contexts of residential users. Finally, the second set of attributes likely to affect observed adaptive outcomes are those factors that do not directly relate to the resolution of a problem, but instead mediate its effects on the chosen measure of success. For instance, insurance and social relief programs do not directly resolve the technical problems that arise as a result of a disturbance, but instead provide resources that allow actors to cope with the effects of that disturbance.

4.0 DISCUSSION AND APPLICATION

In what follows we briefly demonstrate how the adaptation framework can be used to analyze adaptation in the context of sheep farming in Northern Norway. Pastoralists in the coastal region of Northern Norway have faced environmental challenges for centuries. The long winter and short growing season mean that these actors must devise and implement strategies to maintain their herds over the lengthy, but often unpredictable winter months. The Sámi reindeer pastoralists have solved this problem with extensive nomadism, migrating with their reindeer between seasonal pastures. Sedentary farmers, on the other hand, must make important choices about how to maintain their herds in a limited area subject to variable climatic conditions.

Sheep farming in Northern Norway is characterized by four important periods. First, sheep are born in the spring (April or May), and then sent out to mountain pastures until autumn. Breeding is typically controlled so that the newborn sheep will be ready to graze at the onset of the growing season and benefit from the highly nutritious budding plants in mountain pastures. Some farmers have also begun to employ breeding strategies that select for traits to increase revenue by either increased litter size (i.e. triplets), or alternatively smaller litters that tend to have higher individual slaughter weights (Nielsen, Steinheim and Mysterud 2013). While sheep graze in mountainous areas during the spring and summer, farmers use their land in low-lying areas to grow hay that is subsequently stored to feed their overwintering herds. After sheep are brought down in the autumn, a large fraction of the summer herd is culled and sent to local and regional slaughterhouses; while the remaining mostly female sheep are maintained over the winter months to begin the cycle anew,

Over the winter, sheep are kept in barns. They are maintained using some combination of hay from the autumn harvest, purchased hay or industrial feed, and winter grazing. Farmers can also supplement hay supplies with purchased industrial feed. Traditionally, the winter months were the most precarious period for sheep farmers as their livelihoods depended upon their ability to maintain sufficient herds despite variations in hay production driven by a variable climate. Although today the risks are less dramatic, the choices that farmers make can have a significant impact on the financial viability of farming operations, particularly in the context of disturbance.

Sheep farmers have developed a variety of proactive and reactive adaptive strategies to provide for their winter herds. Proactive adaptive strategies tend to focus on augmenting supplies of winter feed by enhancing the productivity of existing fields or expanding production on additional land; although a small number of farmers have also chosen to raise more robust breeds better suited to winter grazing. The so-called "Viking sheep" is smaller and trades at a discount to its more traditional cousin, but requires considerably lower levels of winter maintenance. Productivity enhancements tend to focus on drainage as high levels of precipitation associated with a coastal climate often lead to waterlogged fields that limit accessibility for tractors. Over time, the use of mechanized harvesting techniques on waterlogged fields can lead to soil runoff that lowers the overall productivity of a plot.

Reactive strategies, on the other hand, tend to be triggered after the autumn harvest, when farmers are able to estimate the number of sheep that can be maintained based on the amount of harvested hay, with barn space acting as an upper limit on the size of the overwintering herd. . When farmers identify a gap between hay harvests and this upper limit, they pursue one or more reactive adaptive strategies. First, farmers can purchase additional feed to address this gap and maintain herds at desired levels. This can come in the form of hay from other farmers or regions in Norway. Second, they can manage the size of the winter herd by selling a larger number of sheep for slaughter. Third, they can choose to put sheep out for winter grazing and hope that this can compensate for any gap in food supplies. Although the latter involves some risk, farmers are typically able to acquire additional feed (albeit at a premium) if conditions prevent winter grazing. Finally, Norwegian policies favour larger winter herds as farmers are subsidized for each sheep they own on January 1st.

To investigate the factors that affect individual-level adaptive processes, we conducted semi-structured interviews with sheep farmers and agricultural extension officers in Vestvågøy municipality in the Lofoten region of Northern Norway. Vestvågøy has a generally mild climate despite its Arctic location with average summer temperatures around 11°C, and winter temperatures just below zero. However, there is considerable historical and contemporary variability around these figures, which have a significant impact on farming operational decisions and performance. It has been estimated that Vestvågøy could support 30 to 40 thousand summer sheep, although farmers have kept summer sheep well below this carrying capacity (Figure 3). Between 2000 and 2010 summer sheep increased from 15 to 17 thousand, before falling back in 2010, a trend which is replicated to a lesser degree with winter sheep.

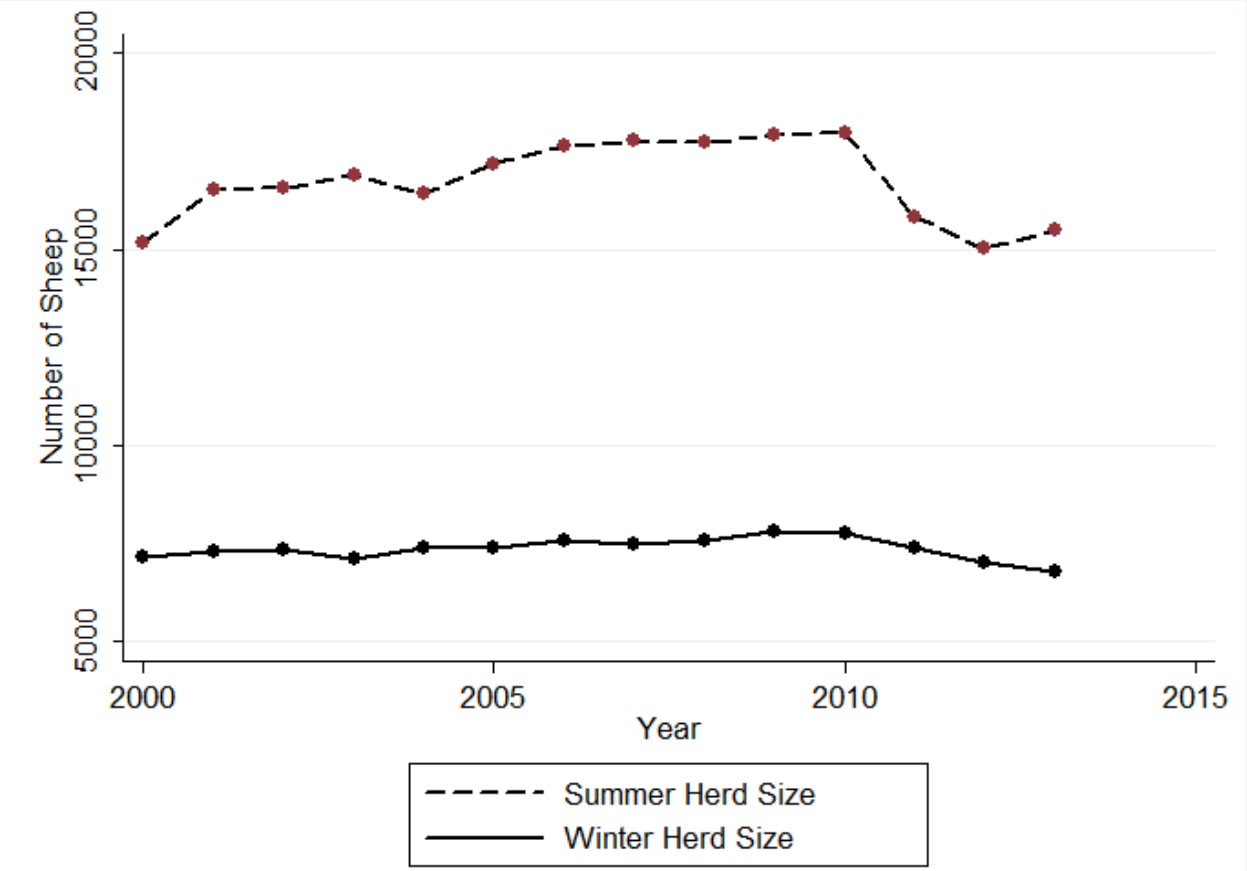

Figure 3: Number of sheep maintained in Vestvågøy

The farmers interviewed as part of this study generally did not view climate change as a significant threat to farming operations, but did suggest that their operations are sensitive to climate variability. All things considered, most farmers believe that in the long run their operations would benefit as a result of a prolonged growing season; a claim which is generally validated by national studies indicating that a 1º C increase in mean annual temperature could result in a 10% increase in profit from increased slaughter weights and stocking rates (Johannesen, A. B., Nielsen, A. and Skonhoft, A, 2013). In fact, farmers were far more concerned about the costs and availability of labour during the lambing season and the re-growth of bushes and trees on summer pastures. According to farmers temporary labour costs have increased dramatically in recent years as a result of completion from with the oil industry and high costs of living. The re-growth of bushes and trees on summer pastures is also a concern as this limits grazing opportunities for sheep, and may be accelerated by climate change. Finally, all farmers reported concerns with the stability of state subsidies that constitute a large fraction of their earnings from farming operations, and other institutional constraints. Most notable among these are land price controls and a complicated estate land transfer system that appears to discourage some farmers from making investments on the productivity of their land. This plays a role in reactive adaptation processes discussed below.

4.1 Proactive adaptation processes

A general model of farmer proactive adaptation process is outlined in figure 4. Farmers interviewed as part of this study clearly identified winter hay production as an important problem for their operations. Recognition of this problem seems to be facilitated by a general understanding (A7) of the underlying variability of the local climate regime, as well as past experiences (A3) with climate variability. In fact, even farmers with only a few years of farming experience reported considerable variability in climate and production. Next, farmers indicate that their search for adaptive strategies tends to focus on two main sources; strategies they have used in the past (A3) as well as information provided from a variety of formal and informal farmer networks (GS3), with older farmers tending to emphasize the former over the latter. Important differences, however, begin to emerge as farmers shift to evaluate the two main identified alternatives; drainage and leasing additional land. Older farmers (A2) whose heirs are unlikely to continue farming operations (A8), and in the context of country-wide agricultural land price control (GS4) evaluate alternatives on the basis of relatively short-term and risk-averse basis. In contrast, younger farmers with potential farming heirs tended to adopt a longer term perspective, and were willing to make investments involving risk. As a result of individual financial resources, credit (A2) and in the presence of a generous and supportive government subsidy regime, farmers face few constraints in selecting their preferred adaptive strategy.

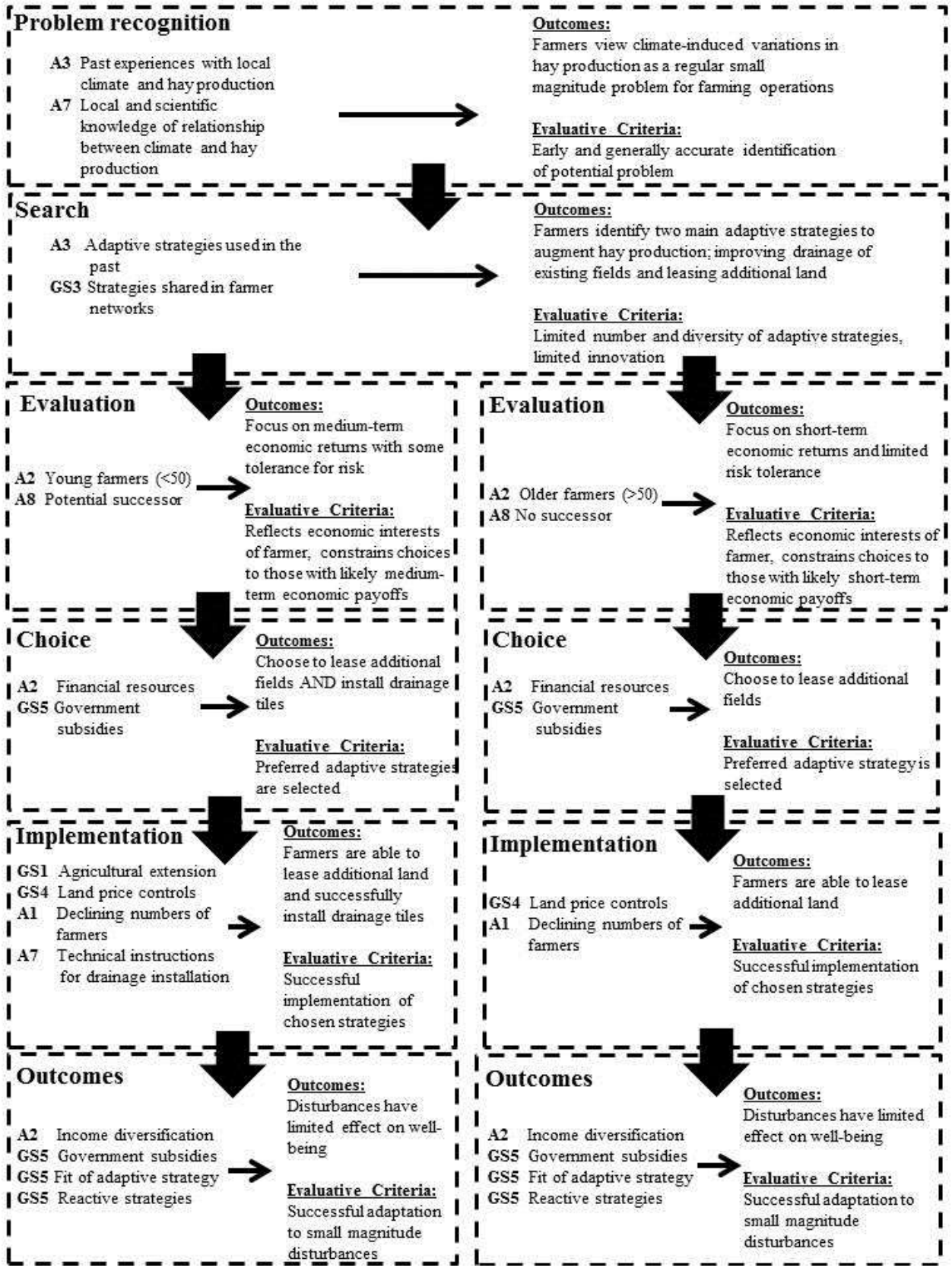

Figure 4: Proactive adaptation to disturbance

Implementation of chosen proactive adaptive strategies also appears fairly straightforward. The younger farmers that choose to install drainage tiles are able to access technical information (A7) about how to correctly install tiles via formal farmer networks (GS3); while land price controls (GS4) coupled with declining numbers of farmers (A1) means that old and young farmers are easily able to find additional land to lease to expand production. Finally, the interviewed farmers indicate that when disturbances do occur they have little impact on their overall socioeconomic well-being. It does; however, appear that this may be as much, if not more, the result of household-level income diversification (A2) and supportive government subsidies (GS5). Nonetheless, both drainage and production on leased land can reasonably be seen as adaptive strategies that fit (GS5) problems associated with hay production and make at least marginal contributions to the socioeconomic wellbeing of farmers.

4.2 Reactive adaptation processes

The reactive adaptation sequence is somewhat different than proactive adaptation since disturbances arise prior to any actions on the part of affected actors as shown in figure 5. Fortunately farmers are able to easily detect disturbances associated with feed for overwintering stocks when they compare autumn harvests (RS7) compared to estimated individual feed requirements (A7). Farmers identify shortages by comparing production figures to the estimated requirements of a barn at maximum capacity. Given that the autumn harvest immediately precedes the slaughter, the timing of problem recognition is timely. The search for reactive adaptive strategies is largely an individual or household matter with a focus on strategies used in the past; although most also discuss potential operational strategies in a variety of formal and informal farmer networks, including the internet (GS3).

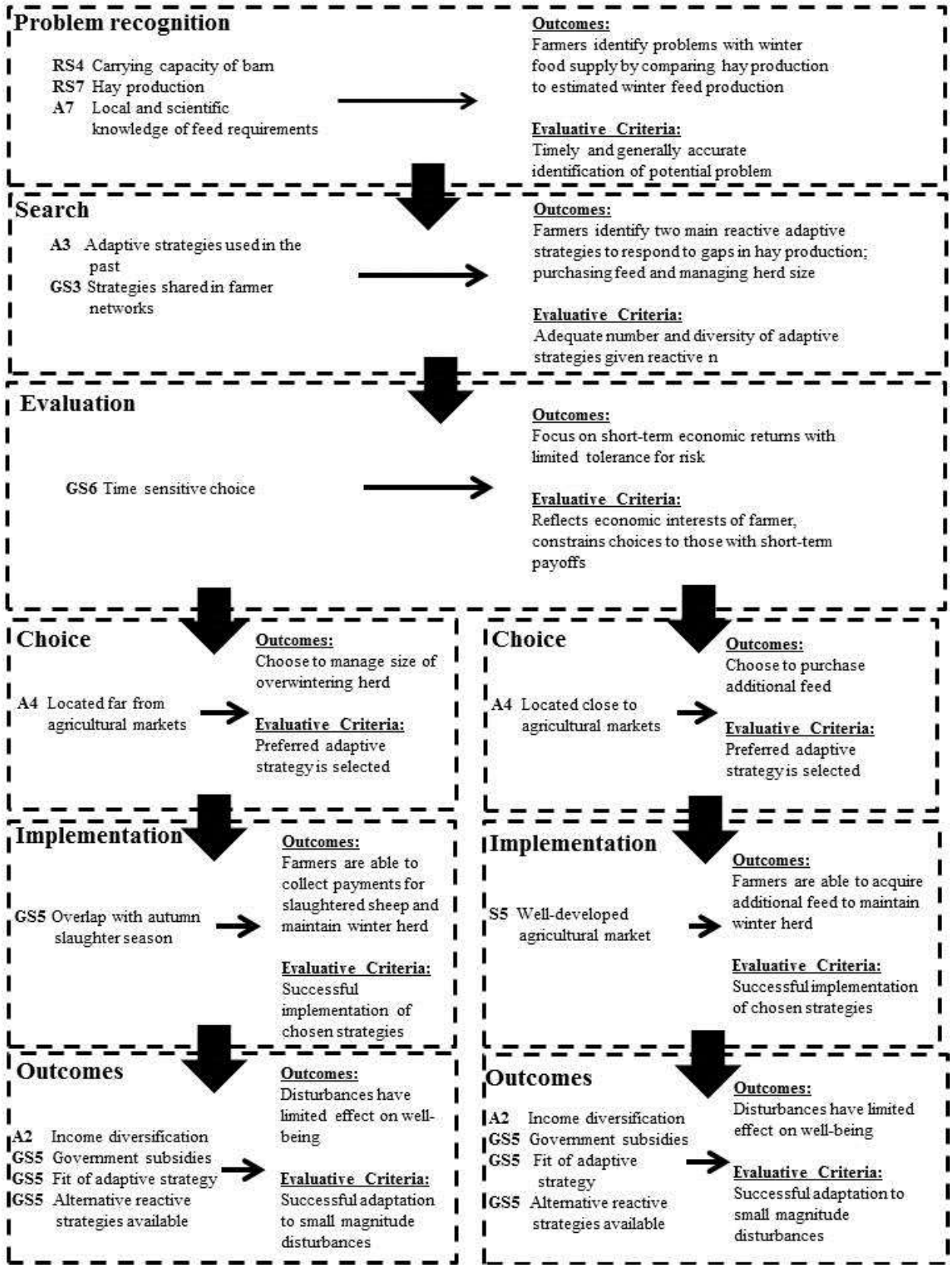

Figure 5: Reactive adaptation processes

Even though problems are recognized and defined prior to the onset of potentially deleterious effects, choices must still be made in a fairly short interval of time which appears to lead to risk-averse evaluations focused on short-term economic returns. It is at this point where differences among farmers begin to appear. Farmers that are located further from agricultural markets (RS9) face considerably higher costs to transport supplies to their farms and therefore choose to manage the size of their overwintering herds. In contrast, farmers located closer to agricultural markets (RS9) face lower transportation costs and thus chooses to purchase additional feed. Implementation of herd size management and feed purchases appears to be facilitated by the general overlap with the slaughter season (RU7), and a well-connected and developed agricultural market (S5), respectively. Finally, once again farmers indicate that disturbance have limited impact on their overall financial well-being, although this as much the result of income diversification (A2), government subsidies (GS5) as it the fit between chosen strategies (GS5) and disturbance. Moreover, even if farmers miscalculate the size of the herd or feed requirements they are able to further manage herd sizes or purchase additional feed, although they may incur additional costs for their mistake.

5.0 Conclusions

The process-oriented framework for the study of adaptation presented in this paper offers unique insights into the factors that drive adaptive choices and outcomes among sheep farmers in Northern Norway. First, it is fairly clear that the financial well-being of farmers in this context is largely the result of supportive government subsidies and diversified livelihood strategies, and less about the specific adaptive strategies they choose. Absent these conditions it is unlikely that these farmers would be able to cope with disturbance, especially considering the relatively small-scale of their operation on marginal land relative to what would be available on global markets. Second, the choice of proactive adaptive strategies is a function of the ways in which farmers evaluate the alternatives; while the choice of reactive strategies is driven instead by the location of a farm relative to agricultural markets which affects the cost of purchasing feed. Older farmers that lack a potential successor in their families appear to favour strategies that generate short-term rewards and involve little risk, and generally fail to invest in the productivity of their land. Thus additional incentives, or alternatively changes to the underlying property-rights system may be needed to encourage these farmers to make productivity enhancing investments on their property.

Finally, the SES framework and process model provide the tools necessary to evaluate how individuals and communities respond to changing social and ecological conditions. The SES framework can be used to identify potentially influential features of the environment that affect choices and outcomes in these systems, while the process model presents a general roadmap of the important stages from the onset of disturbance to adaptive outcomes. Although we have focused on 6 particular stages, these can be modified, enhanced or reduced depending on the topic of investigation. Nonetheless by focusing on processes we are able to better identify areas where policies can be designed to promote more favourable choices and outcomes. For instance, if Norway wants farmers to invest in enhancing the productivity of their plots they might consider policies that allow older farmers to benefit from their investments. The full benefits of the framework will, however, only be realized with additional applications using multiple

methods of inquiry to better understand the factors that affect adaptive processes under variable social-ecological conditions.

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