A STUDY OF RESILIENCE OF THE URMIA LAKE BASIN IN IRAN WITH AGENT-BASED MODELING (ABM)

by

Farzaneh Davari
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Computational Social Science

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DEDICATION

In loving memory of my parents, this dissertation is a dedication to Shams Langeroodi, the iconic and prominent poet and artist, my love and husband, and Elyana, the light, energy, and hope of life, my daughter.

ACKNOWLEDGEMENTS

First and foremost, I am extremely grateful to my dissertation committee for their indispensable academic support. I would like to thank my esteemed supervisor and chair of the dissertation committee, Dr. Robert L. Axtell, for his continued precious scholarly guiding my work. I cannot thank Dr. William G. Kennedy enough for his kindness, incredibly thoughtful comments, and constant support. I owe my learning during my Ph.D. studies to Dr. Andrew Crooks; from the introduction course, to the time he was my supervisor and chair of the committee prior to his departure from George Mason University, and now the member of my committee. Thank you for always spending the time to improve my understanding of issues that I face with kindness and genuinely.

I would also like to thank the academic program administrator, Ms. Karen Underwood, who has tirelessly supported my studies with her kind, responsible, problem-solving, and supportive personality. I would like to express my gratitude to the Provost Office for the support of my dissertation through the Dissertation Completion Grant. I would like to thank the Department of Computational and Data Sciences for all the academic and financial support that I received during my studying.

My special appreciation goes out to my family, husband, daughter, sisters and brother, and my friends for their encouragement and support all through my studies.

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LIST OF ABBREVIATIONS

Agent-Based Modeling .... ABM
Agent-Based Modeling .... ABM
Artificial Neural Network .... ANN
Computational Social Science .... CSS
Controlling Management .... CM
Equivalent Productivity Coefficient .... EPC
Ecological Resilience of Natural-connector .... ERNC
High Water Demand .... HWD
Integrated Water Resource Management .... IWRM
Iran Static Center .... ISC
low-resilient in land-owner resilience status .... lr
land-degradation-class 1 .... ldc1
land-degradation-class 2 .... ldc2
land-degradation-class 3 .... ldc3
land-degradation-class 4 .... ldc4
Low-resilient in system resilience status .... LR
Low Water Demand .... LWD
Max Number of Links of the Network (max-degree) .... MAXNLN
Natural-connector Ecological Threshold (agent-in-network-ecological-threshold) .... AET
Network Resilience Threshold (network-ecological-threshold) .... NRT
No-management .... NM
not-resilient in land-owner resilience status .... nr
Not-resilient in system resilience status .... NR
Number of Links of a Natural-connector .... NLNC
Organization of Agriculture-Jihad .... OAJ
resilient-owner in land-owner resilience status .... r
Resilient in system resilience status .... R
Resilience-building management .... RB
resilient-cooperating in land-owner resilience status .... rc
resilient-leading in land-owner resilience status .... rl
Royal National Institute for the Blind .... RNIB
Regional Water Authority .... RWA
System Dynamic .... SD
Social-ecological Complex Adaptive System .... SECAS
Social-ecological System .... SES
Sense Of Coherence .... SOC

Semi-resilient in system resilience status .... SR
Transferred in system resilience status .... T
Timesteps .... TS
Timesteps 0 .... TS0
Timesteps 1500 .... TS1500
Tipping Point .... TP
Tipping Point 1 .... TP1
Total biocapacity .... total-bio
United Kingdom .... U.K.
United States Environmental Protection Agency .... EPA
Urmia Lake Basin .... ULB
Urmia Lake Restoration Program .... ULRP
Urmia Lake Restoration Program National Committee .... ULRPNC

ABSTRACT

A STUDY OF RESILIENCE OF THE URMIA LAKE BASIN IN IRAN WITH AGENT- BASED MODELING (ABM)

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Social-ecological systems (SESs) consist of diverse ecological parts and units, individuals, groups, and organizations that constantly interact with each other, which in turn cause shocks and disturbances, and instigate changes. The changes in the SESs as the effects of the disturbances to the system are unknown and uncertain due to the dynamics that take place within nested hierarchies via self-organization and learning. For these systems, one concern is whether or not the system and its parts are resilient and can retain their structures and functions when they receive disturbances and shocks.

This research explores the bottom-up adaptive resilience within SESs through self-organization and learning for the Urmia Lake Basin (ULB) in Iran that has gone through a drastic drought process. The Urmia Lake Restoration Program (ULRP) was launched as a national priority plan in 2014. Considering the complexity of ULB, it is needed for any restoration programs, including ULRP, to address the resiliency of the ULB as a SES. Generally, resilience-thinking and resilience-building have found their way into the

management of SESs. However, the existing controlling management approach with the worldwide growing political power-based corruption, including Iran, makes it necessary to include institutional management systems in the resilience study. This research examines the resilience of SESs, specified for ULB, under three management system types to understand the effect of politically motivated institutional management. They are No-management (NM), Controlling Management (CM), and Resilience-building (RB). Methodologically, this research utilizes Agent-Based Modeling (ABM) to capture the nested dynamics within and between the social and ecological subsystems. For the temporal and spatial scales, I programed an Agent-Based Model called MY-VIRTUAL-ULB, which is a virtual world. This research and its findings are useful for policymakers and managers, especially in the ULB, and academic researchers in resilience studies of SESs.

This research conceptually, contextually, and methodologically departs from the dominant established resilience studies. Conceptually, I study resilience as the capacity and property of individuals and the system in the particular case of the ULB. In the established resilience studies of SESs, resilience is the property of the systems and communities rather than individuals. Moreover, I apply a bottom-up integrative approach at all levels within and between social and ecological components. In the dominant resilience studies, two subsystems are studied separately and integrated at the system level. My research includes situations with political conflict and power-based corruption, where controlling management takes over. The resilience studies exclude this situation from their studies. Applying a bottom-up ABM enables this research to implement its integrative approach and promotes the application of ABM in resilience studies, in which system Dynamic (SD) simulation is dominant.

The findings of this research indicate that the resilience status in the ULB is uncertain and unpredictable. The ULB system resilience evolves as the result of lower levels dynamics. Individuals of the social and ecological subsystems have diverse inherited resilience states. The resilience status of ecological individuals plays role in holding or releasing disturbances. The resilience status of social individuals contributes to adapting to the changes through self-organization and learning. The resilience status of social individuals changes according to the results of the adaptation process.

These findings suggest that the resilience of the system and individuals do not always move in the same direction. While the system is in a resilient state, the resilience status of individuals of ecological and social subsystems affects the lower level dynamic. When the disturbances to the system exponentially grow, the system gradually loses its structure and function by decreasing the population and the productivity of lands. In this process, as the population is declining, the individuals are becoming polarized for their resilience status. This polarization becomes deeper under the Controlling Management (CM). However, by fully implementing all requirements for Resilience-building management (RB), the system and individuals move towards being resilient together as long as the situation is not changed. This finding suggests when the states of individuals at the ecology and the social subsystems are monitored very closely, the disturbances can be caught in the smallest portion and at the lowest level. This monitoring may keep the resilience of the system and the resilience status of the individuals at the desirable states. This conclusion is supported by the model with the RB management system. However, when the ULB's system loses its resilient state, it faces the emergence of increasing the number of individuals with the higher resilience state and leading position. They survive and thrive and most probably will be the source of further evolution of the system. Under the political conflict and power-based corruption of the Controlling Management (CM) system, the individuals of social and ecological subsystems are limited in their abilities to self-organization and adapt. Therefore, the ULB system under the CM loses the resilience status faster than under the NM system, and the possibility that the ULB transfers to a different system increases.

Even though the ULB system resilience evolves as a result of the dynamic at the lower levels, the resilience status of a system does not reflect the resilience status of the individuals of the subsystems and the resilience of the system cannot be reduced to the resilience status of the individuals of the subsystems either. Besides the substantive and contextual findings, this research concludes that resilience studies require an integrative bottom-up approach and include the conflict situation by applying ABM. Methodologically, this research proves that ABM paves the way to a new understanding of SESs from the bottom up.

CHAPTER ONE: INTRODUCTION

This research addresses resilience in social-ecological systems (SESs), which is commonly identified as the capacity of SESs to retain their structures and functions after receiving shocks and disturbances (Walker et al., 2004). Resilience is frequently characterized by capacities of absorbing disturbances, self-organization, learning, and adapting (Birkman et al., 2012).

Over the past four decades, the definition of resilience has been changed alongside the changes in understanding of SESs from thinking of SESs as having stable states and near equilibrium to co-evolving essence and finally, adaptive cycle (Folke, 2006). Although resilience is not a new concept, resilience-thinking in human-to-environment relationships has become a new way of thinking (Walker et al., 2006) within the emerging field of SESs in response to the complexity of systems with reflexive uncertainty (Schlüter et al., 2012). This chapter addresses some of the challenges within the resilience-thinking to explain and justify the research problems and questions. The chapter includes four sections. Section 1.1 covers resilience-thinking and challenges, Section 1.2 presents the research problems and questions, Section 1.3 presents the research purposes and hypothesis, and the last section of Chapter One (Section 1.4) reviews the research merits of this dissertation.

1.1 The Resilience-thinking and Challenges

Rooted in ecology and natural resource management, resilience-thinking was born when human and environment relationships were viewed as the integrative social-ecological systems, entrenched in highly complex systems with strong uncertainties (Schlüter et al., 2012). In the middle of the 20th century when the world faced rapid environmental degradation, resilience and resilience-building management gained new attention (Chapin, Folke and Kofinas, 2009), highlighting that the conventional approach and methods of studying and managing SESs did not achieve the expected and predicted results (Martin and Schlüter, 2015). In 1999, the Resilience Alliance: an international collaborative leading coalition was formed, which comprises of multidisciplinary research organizations, to promote resilience-thinking within the SESs and exchange experiences (Walker et al., 2006; Resalliance.org, 2019). Resilience-thinking emerged as a subfield of SES studies when scholars and practitioners across disciplines globally gathered and networked to review concepts, approaches, methods, and challenges in SESs and resilience studies. They published edited books and extensive papers (e.g. Embrace-eu.org, 2019; Chapin, Folke and Kofinas, 2009; Berkes, Colding, and Folke, 2003; Gunderson and Holling, 2002; Walker, Salt, and Reid, 2006). For example, from 2010 to 2015, the emBRACE project, was funded by the European Commission to integrate the knowledge-based research and practices across different disciplines to develop a coherent resilience-building approaches and methods (Birkman et al., 2012). The findings of the project published in eight substantive packages of concepts, methods, and case studies (Embrace-eu.org, 2019). For instance, in the first package, which was about resilience-building among communities in Europe, the resilience concept from different disciplines' perspective was discussed, the differences between them were identified, and a typology of resilience was produced by considering the practices in the US and UK. This project indicates how resilience-thinking is taking seriously and how policy makers would like to base the polices on resilience studies.

Still, resilience studies face several challenges and this research addresses some of them under conceptual, methodological, and contextual. The conceptual challenge comprises two issues. As a complex adaptive system, it is expected that resilience to be studied at multi levels, but in SESs studies, resilience has always been studied at the system emergence level (Taylor et al., 2015). In other words, resilience is studied as the capacity and property of systems and communities rather than individuals. The second conceptual challenge in resilience studies this research takes into consideration relates to pragmatically to recognize the ecological connectivity as well as the interconnection essence between human and ecology, which is the distinctive nature of SESs and makes them different from the other complex adaptive systems (see Section 2.1 and Section 3.3). Ecological connectivity, including landscapes and seascapes, which have been fragmented due to land-owner's activities, is in the focus of environmental studies with the aim of ecological reconnections by applying several solutions (UNEP, 2019; Stockholmresilience.org, 2021). Despite the fragmentation of lands, the ecological connectivity functions under the surface of the fragmented landscape across the interconnected corridors through which energy moves (U.S. EPA, 2012). Environmental conservation programs consider allocating corridors at the surface of the fragmented landscape to let the energy pass through. Then, for example, the USA Natural Resources Conservation Services in the Chapter 4 of the Handbook about the Corridors Benefits (nrcs.usda.gov, n.d.) describes some of the environmental services as the benefits of corridors, which include the reduced flooding and soil erosion, improved water quality, increased water quantity, ground water recharge, bank stabilization, and improved air quality. These are some of the known services of connecting through corridors that could be reversed if the ecological connectivity is ignored. The unexpected disturbances in SESs could be studied as the result of movement of energy through the neglected ecological connectivity of lands. Therefore, the energy movement under the surface for ignoring the ecological connectivity, which negatively affects environment and could be the source of disturbances in SESs, is the concern of this research.

Within this ecological connectivity, SESs, also, can be characterized by the coupling the human and ecological, which are strongly interwoven (Holling and Gunderson, 2002; Folke et al., 2002; Schlüter et al., 2012). Dropping the duality of nature and human, which is rooted in ecology and natural resources, is a challenging step toward realizing the world of complexity of the SESs (Waldrop, 1993). For example, in the emBRACE project, even though the complexity of coupled SESs is well recognized, the fourth Working Package (Taylor et al., 2015) is for social resilience because it is believed that the complexity of SESs relates to the social subsystem and needs to be deeply studied in order to manage the SESs. This does not comply with the complexity of integrated SESs because all ecological and social individuals in SESs, are decision- makers who follow their goals (Schulze et al., 2017), even though human being is the core in SESs for its ability to intervene.

The second challenge, academically and pragmatically, is about designing and applying appropriate modeling tools to study SESs in relation to resilience (Schlüter et al., 2012). As complex adaptive systems, SESs are composed of individuals in both ecological and social subsystems that interact broadly, adapt continuously, and organize hierarchically (Levin, 1998). This procedure of individual-based interactions within and between two subsystems cannot be captured through the dominant simulation modeling methodology of System Dynamic (SD) in resilience studies as described in the resilience modeling procedure (Taylor et al., 2015; Berkes and Ross, 2013; Schlüter et al., 2012; Resilience Alliance, 2010). In this method, the social and ecological subsystems are studied separately, the data for each subsystem are aggregated, and finally, the aggregated data from two subsystems are integrated at the system level to understand the resilience behavior at the macro level.

There have been some efforts to address both individuals' characteristics and the dynamics within the integrated SESs. These studies and models are influenced by science of complexity and psychological studies. Even though the individuals' resilience is often the focus of the psychological studies in disasters (e.g. Berkes and Ross, 2013; Matin and Taylor, 2015; Karanci, Ikizer, and Doğulu, 2015), I would argue this has not got enough attention in resilience studies of SESs. In a limited numbers of resilience experiments, the bottom-up individual-based modeling approach, including Agent-Based Modeling (ABM) and hybrid simulations of ABM and SD, have been applied (Bodin and Norberg, 2005; Schlüter and Pahl-Wostl, 2007; Martin and Schlüter, 2015; Taylor et al., 2015). Still, resilience is considered as the capacity of system rather than individuals, which reflects the domination of system dynamic thinking in resilience studies. For example, Schlüter and Pahl-Wostl (2007) explored how the resilience at the system level changed based on the flexibility of actors' activities. Or, in the cases that have been reviewed by the emBRACE project (Taylor et al., 2015), Agent-Based Models were applied in diverse disaster situations, including floods in Central Europe, disaster preparation considering earthquakes in Turkey, and disaster response in Germany, to explore communities' resilience to disasters (Taylor et al., 2015). Acknowledging the ABM's capability for experiment and scenario development, the review by emBRACE (Taylor et al., 2015) highlighted that in resilience studies applications of ABM were relatively few even though the ABM's merits in ecological studies as well as in SESs were well known. Schulze et al. (2017) noted that ABMs have been already widely used to study SESs even though applying ABM in SESs by nature was complex. In continuation of these methodological experimental efforts and taking into consideration that resilience has been studied at the emerging level instead of the multi levels (Taylor et al., 2015), it is necessary to apply a bottom-up ABM approach to understand the mechanism of changing of individuals' resilience within the nested hierarchy of the SESs adaptive dynamic through self-organization and learning, which has not been addressed yet (Berkes and Ross, 2013; Matin and Taylor, 2015).

The other challenge relates to the context to which resilience has been studied and applied, which is mostly for resilience management (Resilience Alliance, 2010) and sustainability (Chapin, Folke and Kofinas, 2009; Folke, 2006). Such a context requires a political and administrative intention to make the SESs resilient. However, it is not always the case, in certain situations there are the cases in which the SESs are managed within political conflicts. Conflicts have been addressed and studied in SESs and resilience, which are mostly either over different types of using common resource or between individuals' and system's preferences. For example, Kennedy et al. (2010) addressed the conflicts over two types of pasturing and farming, which competed for land and water uses in East Africa. Wise and Crooks (2012) modeled the conflict between two types of land uses, the agriculture and urban development in New Mexico that competed for land and water. Magallanes Reyes (2015) modeled how social conflict might be produced as the result of water scarcity. To manage such conflicts, policy studies concentrated on the role of institutions, including how to manage the conflict between short-term and long term uses of resources to prevent the social-ecological systems from collapsing. For example, institutional constraints were required to prevent over-hunting in North Canadian communities while keeping their hunting culture and saving ecology for their livelihood (Birkman et al., 2012). In Urmia Lake Basin, also, the conflict between Regional Water Authority (RWA) and Organization of Agricultural-jihad (OAJ) is addressed by a group of scholars (Anbari, Zarghami, and Nadiri, 2021) in an ABM-ANN simulation modeling for a specific plain, which is Shabestar-Sofian Plain (SSP), through analyzing three projects. Their simulation model is built on the study by Khatibi et al. (2020), in which they justified why the farmers and water users should not be blamed and the ULB, instead, needed a proper restoration program with the participation of water users as the main decision-makers in the process of planning with a proper service providing and training system (Khatibi et al., 2020). Therefore, in the simulation modeling, Anbari et al. (2021) include the governmental institutions that involve in water governing in the regions in addition to farmers and suggested a combination of them to meet the two organizations' and farmers' objectives. However, various contexts of political conflicts, including the situation where political instabilities and power-based corruptions, as explained in Section 2.1, interfere with plans for sustainability and resilience-thinking, are excluded from the resilience studies because the essential components for system surviving are lost and cannot be substituted (Chapin, Folke and Kofinas, 2009).

1.2 The Research Challenges and Urmia Lake Basin (ULB)

This research is motivated by the Urmia Lake Basin (ULB) in Iran that has faced an unprecedented disturbance. Even though the restorability of the lake is uncertain, the nationwide program of Urmia Lake Restoration Program (ULRP) was designed and the implementation process started in 2014. The review of ULB and ULRP from complexity perspective and the findings, which are presented in Chapter Three, indicate there is a need to study resilience status of ULB. The ULB resilience study faces the same challenges that are addressed by this research. Concentrating on restoring ecological component of ULB by controlling people in ULRP, emphasizes the necessity of considering the unity of ecological and social components in the resilience-thinking study. The attempt to restore the ULB within a controlling top-down management system makes it important to understand what the resilience of a SES is and how it changes and evolves under controlling management system in compare with resilience-building approach. In addition, people in ULB are diverse and they believe they could have done better without such a controlling top-down management system that constantly order them what to do and change their orders daily because of the widespread conflicts among governmental organizations as well as the power-based corruption. Therefore, the resilience study of ULB, which is necessary, faces at least the same three challenges of resilience studies that are addressed by this research.

1.3 Research Problems and Questions

To address the resilience-thinking challenges, this research categorizes them into a triple of conceptual, methodological, and contextual research problems by taking into consideration of Urmia Lake Basin (ULB) situation. Conceptually, this research is concerned with individuals' resilience in SESs, specifically with what the resilience of individuals and systems are and how they change within the nested hierarchies as a result of self-organization and learning.

Methodologically, the problem focuses on how an individual-based bottom-up approach can model the mechanism of changing of individuals' resilience within a nested social as well as ecological hierarchy of the SESs adaptive dynamic through self-organization and learning, as will be discussed in Section 2.1.

Contextually, this research addresses the political conflicts and instabilities as well as power-based corruptions, which interfere the sustainability and resilience thinking. Urmia Lake Basin (ULB) in Iran, which has been in drying process, was the motivation for this research and serves as the case to understand how this means in the institutional management system (see Chapter Three).

Based on this problem definition, the main research question is what is the resilience status of ULB and how could it be modeled?

This question can be broken further down into three specific questions:

1) What is the resilience status of individuals and entire system of ULB and how does it change within an adaptive system?

2) How could the resilience of ULB be modeled within a social-ecological adaptive system?

3) How does the power-based corruption management system affect the resilience of ULB?

1.4 Research Purpose and Hypothesis

This research explores the bottom-up resilience in SESs through self-organization and learning in a political conflict context, specified in ULB. This research hypothesizes that the resilience of the ULB is uncertain and unpredictable. The ULB system resilience property evolves as the result of lower levels dynamics. Individuals of social and ecological subsystems with diverse inherited resilience states adapt to the changes through self-organization and learning. The resilience of the system and individuals do not always move in the same direction. When the system loses its resilience status, the individuals with high resilience state emerge. They survive and thrive and most probably will be the source of further evolution of the system. Under the political conflict and power-based corruption management, the ULB loses its resilience status faster, and the possibility that it transfers to a different system is higher than the situation where the state has no role in the managing of the system.

The research hypothesis is based on four distinct features. First, the research's approach is a bottom-up, which facilitates the understanding of how system's properties can evolve as the result of lower levels dynamics as well as how individuals' properties change within the nested systems' dynamic. Second, the social-ecological system, methodologically, should be studied as an integrated system, which means there should not be any need to synthesize the results of two social and ecological subsystems. Moreover, this research applies ABM as the bottom-up modeling approach for at least three reasons, as will be discussed in Section 2.2). Even though this research proposes and applies ABM as the bottom-up approach of the methodology, the process cannot be inferred as the "unidirectionality" of the process (Epstein and Axtell, 1996). As emergence occurs from both directions of micro and macro hierarchy, it reflects the nested levels interactions of the SESs. This system approach is abstractly reflected in Figure 1, in which the actions by and interactions among three types of individuals take place at the bottom of the system and pass through the levels.

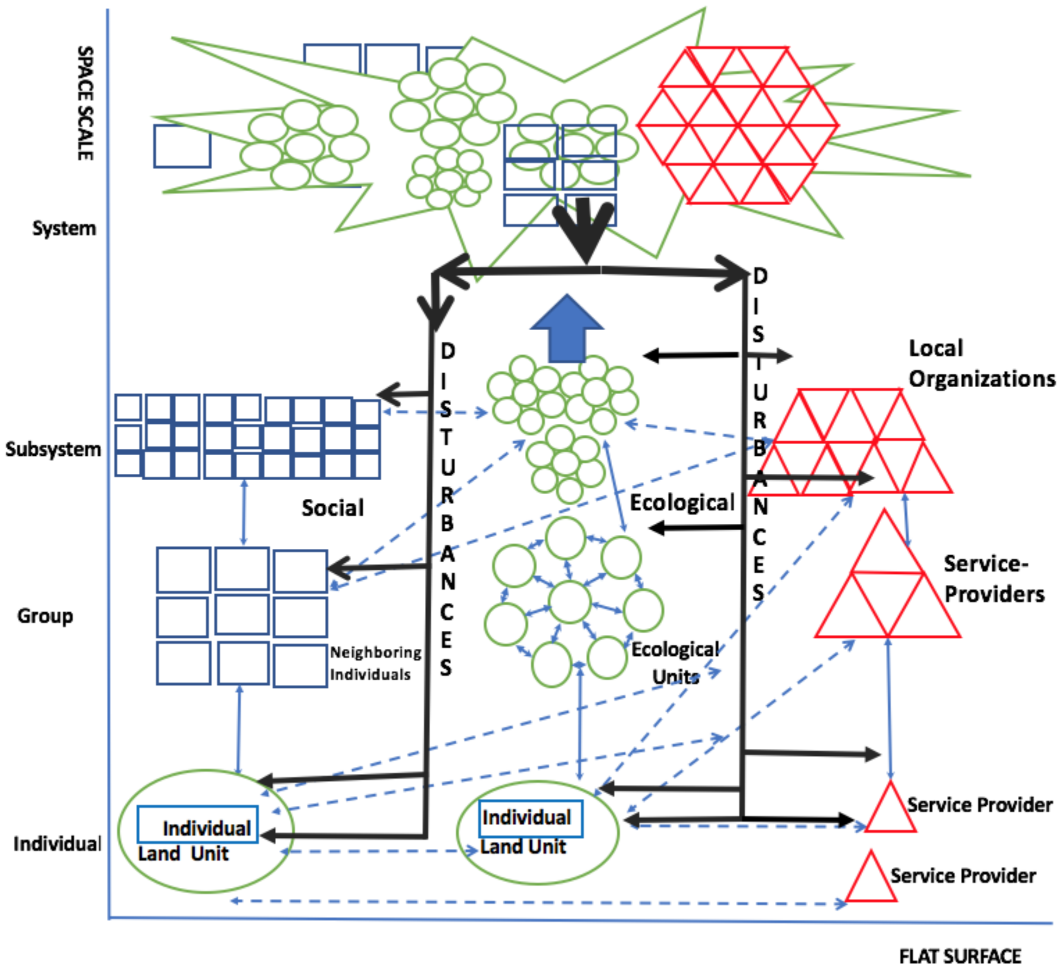

Figure 1. Summary of the system concept for the research

Third, resilience is considered as the property of individual's as well as the system's. As discussed in Section 1.1, in some of the studies with the integrated approach to SESs, both individuals' characteristics and the dynamics within the integrated SESs have been addressed (Berkes and Ross, 2013; Matin and Taylor, 2015; Karanci, Ikizer, and Doğulu, 2015; Bodin and Norberg, 2005; Schlüter and Pahl-Wostl, 2007; Martin and Schlüter, 2015). Still, resilience is considered as the capacity of system rather than individuals and this relationship needs to be studied and explored. For example, expressing the connections between individuals' as well as households' resilience to communities, Berkes and Ross (2013) note that these relationships between levels may not always match, which will be explored by this research. With this procedural definition, this approach should be recognized as a "beyond methodological individualism" (Arrow 1994; Epstein and Axtell, 1996), which emphasizes the methodological approach of micro and macro interlink. Fourth, the contextual situation reflects political conflict, rather than a well-established resilience-building management, as discussed in Section 1.1. As it will be discussed in Section 2.2, under the political conflict situation, in which transparency is pushed back and the power-based corruption increases, controlling management takes over. Understanding resilience under this contextual situation is explored by this research.

The last two aforementioned characteristics are supported by psychological resilience studies, including the resilience study by Matin and Taylor (2015) that indicates resilience could be as much as individually inherited that contextually learnt. This will be discussed in Section 2.1. Moreover, these two features are supported by the individuals' and groups' behavioral approach, in which behaviors of individuals and social groups form in a two-way process, and social cultures and behaviors are created by individuals' perceptions and decisions (Kennedy, 2012).

Therefore, this research hypothesizes that in a social-ecological complex adaptive system, individuals in both ecological and social subsystems have different resilience capacities, and in an interactive adaptation process individuals as well as the system, through self-organization and learning, enhance different levels of resiliency that are required for either keeping the system's structure and function or transforming it to a new system, in which both human beings and ecological subsystems can live together as one single evolving system. More specifically, a system may not gain its resilience without giving enough space to individuals to go through learning and self-organization. This process may force institutions to adapt themselves to the changes through the individual service-providers' involvement if the institutions have not previously presented their capabilities of evolving, or if the service-providers have not been corrupted at the level that their actions force the system collapse.

Based on the research problem and hypothesis, the research purpose is to understand and develop theory for the bottom-up procedure of individual-based resilience-building -beyond methodological individualism- through self-organization and learning in a SES within the politically corrupt context by utilizing ABM simulation. The applied procedure for exploring by an ABM is given in Chapter Four.

1.5 The Research Merits

This research is about resilience in social-ecological systems, which is not a new subject, but specified for ULB. The main value of the research relates to its integrative conceptual and methodological approach. Taking a bottom-up approach beyond methodological individualism, this research considers resilience beyond the emergence level, in which resilience is studied at individuals as well as subsystems and system level, studies social-ecological system as an integrated complex adaptive system at different levels instead of integrating the results of separately studied subsystems at system level, and experiments the resilience procedure through self-organization and learning approach in a political conflict context.

While this research highlights the value of studying the resilience of the Urmia Lake Basin (ULB) it shows how the management systems, especially the current Controlling Management (CM), affects the resilience of the ULB, and how it can be improved by taking the comprehensive approach and service providing method that is suggested by the Resilience-building Management (RB) system.

This research develops several academic merits in the field of resilience study of SESs and Computational Social Science (CSS). First, in this research resilience is an informal process that follows an unknown path within a political conflict context. Therefore, it is expected this research produces some new procedural content to the resilience.

Adaptive cycle approach has promoted resilience studies to cross scale and multilevel hierarchy approach. Applying ABM at both levels of individuals and subsystems in the social-ecological linkage process in this research will advance the methodology of the resilience studies. ABM has proven its capacity for understanding human to ecology interaction in an evolutionary process from bottom-up approach as an artificial world (Epstein and Axtell, 1996), however; multilevel application of ABM is the promising in the resilience studies (Schlüter et al., 2012). Although Schlüter and Pahl-Wostl (2007) have applied the bottom-up ABM approach in SESs as the integrated systems for resilience, this research distinguishes its approach with considering the resilience as the capacity of individual’s as well as system’s that can be enhanced through learning and reorganization process. This is the second merit of this research, which fulfills the need to develop Theory of Adaptive Change, as highlighted by Holling et al. (2002) in Panarchy, by developing theory of resilience procedure within the “inherently integrative” approach.

In addition, applying ABM in complex adaptive system would strengthen the Computational Social Science (CSS) by presenting the capacity of simulations, specifically the bottom-up approach ABM, to capture the complexity relationships between the psychology of individuals at the micro level and social phenomena, including groups and institutions, as well as system at the macro level. Understanding this dynamic always has been a concern of social science studies, especially between psychology and sociology. Secondly, it increases the social knowledge in the field of resilience by taking into consideration of the integrated social-ecological units.

Besides, the following values can be highlighted as the result of applying an ABM for a bottom-up resilience thinking in social-ecological adaptive system:

- highlighted the need and value of resilience study of the ULB;
- identified the effect of management system in managing the resilience of ULB;
- improved the knowledge about how resilience could form, which may affect the ULRP approach for ULB;
- promoted the individual-based approach in resilience-thinking by considering resilience as individual property as well as the system’s in social-ecological complex adaptive system;
- increased the ability to consider the social-ecological system as the integrated system;

- increased knowledge about complexity of social-ecological system and application of ABM in resilience-thinking and policy making;
- promoted the application of resilience for political conflict as well as the real-world situation;
- strengthen Computational Social Science (CSS) by presenting the capacity of ABM simulation to capture the complexity relationships between psychology (individual) and sociology (system) as well as ecology;
- demonstrated the capacity of CSS to study resilience for SESs; and
- proved the role that CSS can play in resilience studies for SESs to foster departure from disciplinary approach.

CHAPTER TWO: LITERATURE REVIEW

Resilience concepts, methods, and modeling closely relate to the conceptual and methodological changes in human-to-environment relationships and SESs over time. Moreover, as Schlüter et al. (2012) comprehensively reviewed, SESs have been developed out of the separate disciplines and applications of ecological fields of fisheries, wildlife, rangelands, agricultural land use, and interdisciplinary fields, including complex adaptive system theories, resilience, and economy, as well as based on the global pragmatic cases. Therefore, resilience concepts and modeling interlink with the SESs and complex adaptive science while they are contextual. In this section, the literature of concepts, modeling, and context for this research are briefly reviewed and respectively presented in Section 2.1, Section 2.2, and Section 2.3. The concepts, theories, and approaches are presented in four Subsections, which are Subsection 2.1.1, Subsection 2.1.2, Subsection 2.1.3, and Subsection 2.1.4. The methods and models are reviewed in Section 2 and presented in Subsection, 2.2.1, Subsection 2.2.2, and Subsection 2.2.3. The last section, which is Section 3, covers a review of contexts in which resilience could be occurred either intentionally with specific resilience-building programs or unintentionally as a necessary process without any specific program of resilience-building.

2.1 The Concepts, Theories, and Approaches

As complex adaptive systems, SESs encompass large numbers of heterogeneous "active elements", which are "diverse in both form and capability" (Holland, 1995), no matter if they are parts of environment or human. These elements constantly are in action and interaction with each other. Uncertainty and surprises relate to the unknown responses of the parts of the complex adaptive systems to shocks and disturbances as well as the interactions of the parts and their continuously changing behaviors within the adaptive process (Gunderson and Holling, 2002). Self-organization and learning are two characteristics of complex adaptive systems, through which the systems adapt, evolve, and transform (Gunderson and Holling 2002; Berkes et al., 2003, Folke, 2002). The nested levels of interactions between individuals, households, and communities in SESs have been acknowledged (Berks and Ross, 2013). With two social and ecological subsystems, SESs are hierarchically structured and strongly connected with various temporal and spatial interactions (Schlüter et al., 2012). The way of thinking about decomposability of SESs to their subsystems affects not only the study method (Simon, 1996; Gallopín, 2006; Epstein and Axtell, 1996; Heppenstall, Malleson and Crooks, 2016), but also the management of the systems (see Section 2.3). With this definition, it is expected that resilience to be studied at multi levels, but in SESs studies, resilience has always been studied at the system emergence level (Taylor et al., 2015). Therefore, the individuals' resilience capacity and their abilities, individually and socially, to learn (Taylor et al., 2015) and organize in response to the changes, which would lead to the phenomenon of emergence in SESs and surprise us, have not received enough attention (Matin and Taylor, 2015).

2.1.1 Social-ecological Complex Adaptive Systems and Resilience-thinking

Resilience has conceptualized out of the contextual cases, however; the most common definition is based on the idea that nature is capable to absorb internal disturbances but human being has treated these disturbances inappropriately, which sometimes has imposed new disturbances to the nature (Folke, 2002). Regarding to where SESs are taken by their resilience capacities, there are three different approaches, which have been collaboratively developed through experimenting, criticizing, and theorizing over time mostly by the same scholars (Folke, 2006). The first approach believes in the stable state in SESs, rooted in early studies in ecology, identifying the resilience concept as the capacity of returning to the previous structure and function. This approach reflects the view of a single stable state equilibrium and behavior near the stable equilibrium. In this approach resilience is known as the resistance to change (Birkman et al., 2012). The second approach assumes multiple equilibrium states of SESs and emphasizes that the SESs retain their structures and functions without mentioning the previous state (Berks and Ross, 2013). The third approach proposes an unknown alternative state, which is reflected in the work of Scheffer et al. (2001) and Scheffer and Carpenter (2003). Observing and analyzing the ecosystems' changes over long periods of time, which has shown that SESs may present one or multiple states, lead to introduce the "alternative state" as the possibility for the cases that face regime shift (Scheffer and Carpenter, 2003; Scheffer et al., 2001). With uncertainty about where the adaptation takes the system, in

Holling's (2003) "adaptive cycle" of "growth, collapse, reorganization, renewal and re-establishment", resilience occurs between two cycles of growth and renewal through self-organization (Holling and Gundrson, 2002; Bekers et al., 2003). Holling and Gunderson (2002) characterized resilience definition by "capability of self-organizing" and "capacity for learning and adaptation" within the adaptive cycle approach (Berkes et al. 2003; Folke, 2006; Chapin, Folke and Kofinas, 2009). Reflecting on Holling's work, which is a turning point in the resilience discourse (Birkman et al., 2012; Folke, 2002, 2006), Folke (2006) expressed the idea of transformation of the social behavior and management if the system could not be returned to its function.

Recognizing ecosystem with two ecological and social subsystems that are integrated has led to a practical method of assessing the system's resilience. Within this approach (Resilience Alliance, 2010; Chapin, Folke and Kofinas, 2009), resilience capacity should be assessed in the ecological component through engaging stakeholders especially from the institutions that involve in the system management. For example, practitioners are instructed step by step to manage the social component through resilience-building management by the Resilience Alliance (2010). As a result, the system could present resilience, which indicates that resilience is the system's property. Moreover, this procedural assessment of system resilience shows that the duality thinking about social and ecological system still persists.

Within the adaptive cycle and based on extensive studies in diverse fields, Chapin, Folke, and Kofinas (2009) conceptualized adaptive capacity, resilience, and transformation with the system dynamic thinking. In their conceptual framework, the system's components, including adaptive capacity and stabilizing feedbacks, respond to external disturbances within a system dynamic, and consequently, the system present its resiliency as one of the possible system's outcome at different temporal and spatial scales. In this conceptual framework, the system's response to the changes depends on how the system's components link across scales and the stabilizing feedbacks. One of the system's capacity is its adaptive capacity that can be enhanced through the mechanism of learning and innovation. The system's resilience contributes to adaptive capacity through the system's mechanisms of feedbacks and "adaptive governance". Adaptive capacity is the actors' as well as groups' capacity, which depends on four other capacities, including the main fundamental capacity of adjusting to change, which is based on biological, economical, and cultural diversity in the system (Chapin, Folke and Kofinas, 2009). Therefore, capacity to adjusting is the property of system or the groups in the system that is aggregated at the system level to make the system resilient.

2.1.2 Resilience-thinking, Systems, Communities, and Individuals

There have been several efforts in resilience studies of SESs to move from system level to communities and individuals. In these studies, the impact of different variables on resilience-building of communities and systems are studied. Some of the variables are the diversification of activities (Schlüter and Pahl-Wostl, 2007); the adaptation and reflexive actions (Otsuki et al., 2017); and the collective actions and trust (Anderies et al., 2004; Janssen and Anderies, 2013). Moreover, self-organization and learning in some of the studies (e.g. Otsuki et al., 2017, Bohensy, 2014) have been addressed. For example, Bohensy (2014) studied the learning procedure in water management and explored how the individuals' and social learning change within the procedure of social and ecological interactions. Still, social learning rather than individual's is the main concern of resilience studies in SESs (Taylor et al., 2015). In addition, the individual's resilience capacity, which is the main target in psychological resilience studies (Matin and Taylor, 2015: Karanci, Ikizer, and Doğulu, 2015), has not been addressed in SESs. Instead, resilience in the SESs studies is considered the property of either community, which is not widely addressed (Berkes and Ross, 2013; Otsuki et al., 2017), or system, which emerges as a result of dynamic within the system. This is the dominant approach in resilience studies (Taylor et al., 2015) and can be found in the most of the studies even when either a bottom-up or a combination of bottom-up and top-down modeling approaches are applied. The example of applying a bottom-up modeling is the study by Schlüter and Pahl-Wostl (2007), and the example of applying a hybrid modeling approach is the study by Martin and Schlüter (2015).

Valuing the community resilience building in case of disasters, which is the core in mental health studies, and for integrating two strands of resilience studies in mental health and social-ecological systems, Berkes and Ross (2013) analytically reviewed the background studies in two fields of ecosystem and local and community. Their work described how psychologists concentrated on individuals and improved the resiliency through community resilience-building process, while in the social-ecological systems the concentration was on the entire system. Explaining how resilience occurred at all levels of systems "from individual to earth", it was shown how targeting community resilience-building led to "self-organizing" and "agency", which could be understood as an equivalent to the adaptive capacity in SESs and could be found as an attribute at all levels of the SESs. For this reason, Berkes and Ross (2013) suggested following the community resilience and considered the ecological component of SESs as the community capital for resilience-building. In terms of transformational change, the value was given to two types of transformation at the community level for SESs as a whole system. First, some transformational change at lower level, such as small forest fires or transformed activities at lower level, might increase resilience at higher level. Second, as the transformation at higher level might be expensive and socially might not be acceptable, the sequential changes at lower level of communities might improve the whole system through feedbacks. For example, at the community level different activities such as tourism or fisheries could be explored for different communities. The diversified activities and increased the communities' resiliency, and consequently the resiliency of the system increased. Even though it was mentioned that resilience occurred at all levels of individuals and households as well as communities, it was explained that the relationships between individuals as well as households with community resilience were not consistent. This was the reason for advocating for community level resilience-building for SESs.

Following the same concept of community resilience-building based on the individuals' adaptive capacity, reflexivity, and communication, Otsuki et al. (2017) applied a biographic story method of 4 farmers in Ghana to examine how individuals' adaptation actions could change cultural, ecological, and political situation through reflections and communication that enabled collective agency of individuals. The research concluded that it was essential to concentrate on community resilience-building for social-ecological system, which could be enhanced through enabling individuals to communicate and reflect on their adaptation actions. One of the major resilience-building activities at community level was proposed by 44mbrace (Jülich et al., 2014). Even though 44mbrace covered all types of resilience, it strongly included the social-ecological resilience management. Supported by the case studies across the European countries, 44mbrace concluded that the community resilience was formed by three external factors of the situation that entrenched the community, the disturbances that a community might receive, and the change that community would face because of the disturbances (Jülich et al., 2014). The degree of resilience of the community was determined by three groups of "capacities and resources", "actions", and "learning". The first group of capacities and resources included "socio-political, financial, human, natural/place-based, and physical" elements. The group of actions included "mitigation, preparedness, response, recovery, and reconstruction". And the learning comprises of "problematizing risk/loss, critical reflection, risk/loss perception, experimentation and innovation, dissemination, and monitoring and review".

Recognizing resilience as an internal attribute of a system that could be disturbed by human activities, Anderies et al. (2004) and Janssen and Anderies (2013) stressed the need to shift from system level to individual's. In their experimental efforts to understand the individuals' decision-making and common-pool management, Janssen and Anderies (2013) argued that resilience/robustness-building of a system imposed cost to individuals, therefore; individuals had to trade-off their individual's costs and the system's preferences. To increase the system's resilience/robustness, they (Janssen and Anderies, 2013) suggested reducing vulnerability of individuals through trust and equality. To understand the individuals' behavioral pattern in resilience-building, Schlüter and Pahl-Wostl (2007) applied an Agent-Based Model and Martin and Schlüter (2015) experimented a hybrid method, which was a combination of System Dynamic (SD) and ABM. In both experiments, resilience was the system property that emerged as the result of some factors such as diversity of activities. For this reason, for the social component, studies and practical management experiences concentrated on how mechanisms of institutions, collective actions (Ostrom et al., 2014; Ostrom, 1998), management regimes (Schlüter and Pahl-Wostl, 2007), and resilience-based ecosystem stewardship (Chapin, Folke and Kofinas, 2009) could enhance the system's resilience. Still, there was a need to understand the mechanism of individuals' resilience changes within the SESs context, as highlighted in psychological studies.

2.1.3 Resilience-thinking for SESs from the Psychological Aspect

Besides the psychological studies at community and system levels by Berks and Ross (2013), Changshen (Birkman et al., 2012) reviewed the psychological studies from the resilience-thinking and complexity perspective for 45mbrace project and published in the first package (Embrace-eu.org, 2019), as described in Section 1.1. The review showed a trend in psychological resilience studies:

1) Focusing on key individual's characteristics that related to psychological resilience, such as meaningful life and positive emotions;

2) Including social-ecological contexts in which individual's experienced stresses; and

3) Moving away from static studies to the dynamic process and focusing on dynamic process at multi-interdependent scales, including individual, family, community. Still, a gap was recognized to provide enough evidences about" interactions and interdependencies "between multi-levels.

Changshen (Birkman et al., 2012) concluded that there was a need for more multidisciplinary and multi-levels qualitative studies and a need for more qualitative studies to explore. In a combination of quantitative and "narrative inquiry" methods, Matin and Taylor (2015) assessed human resilience in a severe disaster situation in Bangladesh after the second tropical cyclone of Aila hit Indian Ocean in 2009. In their quantitative studies, they applied the coping mechanism by using the different conceptual measurement of Sense Of Coherence (SOC) to measure the individual's resilience in the scale of 1-100. Even though, the findings of quantitative studies indicated that some personal's dimensions, such as education and livelihood security, affected the resiliency of individuals, they found out that human resilience was an emerging complex phenomenon in a dynamic process between the individuals and the situation at micro level. In this resilience emerging process, individuals with different life experiences could enhance the same individual's resilience level and at the same time individuals could present different resilience levels even though they had the same life experiences. One of the stories of resilient individuals was the ability to organize and group and encourage the others to act accordingly. In their conclusion, Matin and Taylor (2015) expressed that inherent characteristics such as "self-efficacy" and "optimism" could play role in this emerging process. These findings supported the idea of this research that resilience is the property of individuals as well as systems and could be either inherited or generated over a dynamic process at both micro and macro levels in SESs.

2.1.4 Resilience-thinking from the Management Approach

Central top-down policy making, planning, and management in natural resources has a long history and has been challenged theoretically and practically. Pathologically analyzing the command-and-control management approach in natural resources from the point of view of the SES, Holling and Meffe (1995) explain that historically this approach has been extended to natural resource management when the population was increasing and natural resources were declining. The *Tragedy of the Commons* (Hardin, 1968), concerns how an increasing population would intensify conflict over common-pool resources, such as water, which in turn could create a dilemma between choosing either full individual "freedom" to optimize resources to its benefit by letting some die. Or enforcing a social "extreme coercion" through controlling individuals in their use of resources for the sake of the population. Analyzing practices and experiments 30 years later, Ostrom et al. (1998), published *Revising the Commons: Local Lessons, Global Challenges* and acknowledged the tragedy of commons, but presented how it had been used to justify governmental central control over water as common-pool resources. They challenged both proposed solutions to the tragedy by Hardin and demonstrated what the glob could learn from the local experiments. They showed how a community could be self-organized to use the common-pool resources while requiring a governing institutional evolution, among the other requirements. Since then, many experiments by Ostrom and others have presented that communities are willing to cooperate and act collectively, including the recent study to use *games for groundwater governance* in India by Meinzen-Dick and his colleagues (2016). They show how acting collectively is important to reduce cultivation of high water consumptive crops especially where ground water is used, over which the state has limited power to control.

Folke and his colleagues (2002) compare two types of controlling and resilience-building managements of social-ecological systems. The resilience-building is a “flexible and open to learning” management, which handles the changes slowly. Through this management, which “creates memory, legacy, diversity, and the capacity to innovation in both social and ecological components of the system”, the social-ecological system “sustains when it faces surprises”. In the controlling management, the changes are canalized and the natural disturbances and social memory are suppressed. The mechanisms for creativity and adaptive responses by people are removed, which lead to breakdown of social-ecological system.

2.2 Methods and Models

Modeling is a traditional tool in ecology and natural resources. Over the past 50 years, shifting from the ecological approach to the integrated social-ecological system changed the modeling approach from linear mathematical equation and statistical modeling to computational simulations, including System Dynamic (SD) and ABM. SD is dominant modeling in resilience studies because it assumingly fulfills both aims of modeling (Schlüter et al., 2012), as will be discussed in Section 2.2.2. The limited numbers of applied ABMs in SESs and resilience studies have been mostly used to understand the system, specifically social subsystem, rather than managing (Schulze et al., 2017; Taylor et al., 2015) because the system dynamic thinking still is dominant in these studies. Increasing the application of modeling in SESs, especially simulation models, leads to addressing the challenges in the modeling and the ways to overcome them (Elsawah et al., 2020). This modeling review supports the research proposal for an ABM in an integrative procedure within the beyond methodological individualism (Arrow 1994; Epstein and Axtell, 1996).

2.2.1 Conventional Methods and Models in Social-ecological Systems

Conventionally, modelling was used for understanding the system and managing it within the command and control approach. Holling and Meffe (1995) characterized this conventional modeling approach as a "linear, "cause and effect", and "problem solving", in which a controllable solution to a well-defined problem was assumed. Schlüter et al. (2012) comprehensively reviewed the modeling approaches and compared two conventional and the SES-based modeling and their characteristics in different fields. From the resilience and management points of view, the conventional modeling was based on "simple reference points" and management of resource stocks and condition, not wider ecosystem" while management in SES "involved complex tradeoffs", and "resilience and adaptive capacity" were managed through "stabilizing and amplifying feedbacks within a broader context" (Schlüter et al., 2012). The conventional modeling approach was based on rationality of human beings, certainty, "linear and monotonic", assuming that key variables were known with probability distributions. The conventional modeling, in which mathematics and statistics are widely used, has been challenged for targeting single problem sources, predictability and controllability approach, and neglecting feedbacks as well as for its reductionism, which tries to understand the system dynamic analytically from the system components (Schlüter et al., 2012; Folke, 2006; Walker et al., 2004; Holling and Meffe, 1995; Holland, 1995; Holland, 1998; Gunderson and Holling, 2002).

2.2.2 Computational Modeling in Social-ecological Complex Adaptive Systems

According to Schlüter et al. (2012), modeling in SESs has two aims. The first aim is to understand the structure of two social and ecological subsystems and how the feedbacks within and between these two subsystems identify the system behavior as a whole. The second aim is to suggest strategies to manage the uncertainties in SESs. In 2020, a group of scholars (Elsawah et al., 2020) highlight three ways that modeling, as an effective tool, could help address the issues of SESs systematically and collaboratively. As the first way, the modeling provides a platform to integrate different methods and data. In this way, the modeling formally exhibits the complex adaptive system and captures the system's components, the interactions, and the responses to the changes in the system. The second way that the modeling could help the users is the systematically exploring and assessing the impacts of the parameter changes in the system. The third way is providing an informative science-based platform to exchange knowledge that leads to a common understanding in developing action plans.

Still, modeling for SES faces challenges. One of the very early identified challenges relates to the decomposability of the system. The SESs approach considers the social-ecological system a non-decomposable (Gallopín, 2006), while complex systems are known for their near decomposability (Simon, 1996). Epstein and Axtell (1996) explain that the processes of complex sciences, including social sciences, are not ”neatly decomposable into separate sub-processes” for studying separately and then aggregating to understand the whole system. Indeed, methodologically, it is a challenge in SESs to examine the processes of the entire system when the sub-processes are evolving within the interlinked nested hierarchies. The group of scholars (Elsawah et al., 2020) also address eight grand modeling challenges for SESs. They analyze the reasons and roots of the challenges and suggest ways to overcome these challenges.

The scholars (Elsawah et al., 2020) highlight the epistemological challenge of the modeling in SESs, which is rooted in the disciplinary study, as the first challenge. The second challenge is to model the uncertainty of SESs in an integrative way. The sources of this challenge could be using different types of data, modeling structural uncertainty, and parameterizing the uncertainty. However, they highlight that the structural uncertainty, which relates to the nature of the complexity of SESs, remains a challenge because the uncertainty assessment follows a narrower conventional approach that focuses on data and parameters. Overcoming this challenge, they believe that there is a need for a paradigm shift. They suggest seven methods and techniques that could help to move forward for the modeling SESs. The suggestions include moving beyond the traditional quantitative methods; applying methods to understand the qualitative dimension of uncertainty; applying methods to identify and integrate model structure sources of uncertainty; applying the methods of exploration to understand structural uncertainty; using surrogate modeling methods; employing data analysis techniques to inform uncertainty analysis; consolidating the communication process among model developers and the users. Integrating human and ecology dimensions with different spatial and temporal scales leaves the modelers with a grand challenge. The fifth challenge relates to the integration of the qualitative and quantitative methods and the balance of these two aspects for data collection and modeling. As a complex system, the modeling for SES requires the systematic capturing of changes in SES, which is considered a grand challenge. The modeling in SES roots in ecology and including the human dimension in an integrative way remains a challenge. The elevation and adoption of the modeling in SES for the policy implication still is a challenge. Applying participatory modeling is one of the methods that the scholars suggest to overcome this challenge.

Modeling in resilience studies has been changed as the modeling in different fields of ecology, natural resources, and SESs have been evolving. As discussed in Section 1.2, the modeling in resilience has been affected as the understanding of SESs has been changed from thinking of SESs as having stable state, near equilibrium, and multiple equilibrium states to the “alternative state” and “regime shift” without knowing where the systems transform (Scheffer and Carpenter, 2003; Scheffer et al., 2001). Resilience modeling initially was based on “difference or differential equations”, and “changes in the rates of an environmental variable”, such as grazing rate, present “human behavior” without including the feedbacks, which are crucial for resilience thinking. Out of the models that take into consideration the “nonlinear ecological dynamics” and the effects of the “adaptation” and “learning process” have on resilience, Schlüter et al. (2012) listed some of the models that focused on managing SESs at the alternative state or shifted regime.

The extensive numbers of the models tended to "identify indicators for regime shifts" with the aim of preventing the shift into an "undesirable" state. More recently, the modeling in resilience has focused on social subsystem or human behavior for resilience-building or management.

2.2.3 Simulation Modeling in Resilience-thinking: System Dynamic, Agent-Based Modeling, and Hybrid Models

With the rich theoretical systems and mathematical modeling background, resilience communities are more system oriented by taking into consideration of "interconnections", "alternative states", and "critical ecological thresholds", as explained by Taylor et al. (2015). For this reason, SD modeling commonly is used in resilience studies to understand the system behavior and function. SD is built on "difference and differential equations" and searching for "future state" of the system based on the "actual state" through "nonlinear dynamic" behavior and "feedbacks" at system level through "causal feedbacks" in terms of changes in stocks and flows, which are the forms of representing aggregated system (Gilbert and Troitzsch, 2005; Martin and Schlüter, 2015). However, as complex adaptive systems, SESs are composed of individuals in both ecological and social subsystems that interact broadly, adapt continuously, and organize hierarchically (Levin, 1998). This procedure of individual-based interactions within and between two subsystems cannot be captured through the dominant simulation modeling methodology of SD in resilience studies as described in the resilience modeling literatures (Taylor et al., 2015; Berkes and Ross, 2013; Schlüter et al., 2012; Resilience Alliance, 2010). The challenges of applying SD modeling and data integration procedures to understand resilience behavior at system level from two subsystems were explained in Sections 1.1. In resilience field, three levels of individuals, communities, and systems as well as their relationships have been studied but mostly separately within the social subsystem to develop theory. This means that resilience factors at micro level in social subsystem are studied and then, the acquired knowledge can be used with high confidence at the social-ecological system level. As an example, this method has been applied in the meta modeling of community resilience building of 54mbrace project (Taylor et al., 2015). As discussed in Section 1.1, there have been some efforts to address both individuals' characteristics and the dynamics within the integrated SESs. However, it is commonly accepted that ABM is a suitable model for social subsystem of SESs to develop theories while SD has to be used for planning and management (Taylor et al., 2015). According to Schlüter et al. (2012), out of 29 reviewed models in SESs resilience, "69% used difference and differential equations to formulate the model, 24% used rule-based models, including ABM, and 24% state and transition models, including SD" (Taylor et al., 2015). Meanwhile, reviewing the applied ABMs in SESs, their achievements and challenges, Schulze et al. (2017) noted that ABMs have been already widely used to study SESs even though applying ABMs in SESs by nature was complex, especially for parametrizing and analyzing the results. ABMs are mostly used to improve understanding of SESs rather than solving real world problems. Even though there are some successful examples of predictability in ecological component of the SESs, the complexity of decision-making of the social subsystem of SESs and very specific modeling challenges, including conceptualizing, sensitivity analyzing, verifying and validating, just mention a few, are barriers of application of ABMs in SESs.

2.3 Contextual Resilience-building Management System

Contextually, this research addresses the situation with political conflicts and instabilities as well as power-based corruptions, which interferes with the plans for sustainability and resilience thinking. This contextual situation is currently excluded from the resilience studies and management, as explained in Chapter One. Moreover, under the political conflicts, some of the conditions that are required for resilience-building cannot be met, including managing collective action, institutional evolution, and an open environment for self-organization and learning. Urmia Lake Basin (ULB) in Iran, which had gone through a drying process, is the contextual motivation for this research and its background studies provides information to understand one of the political conflictual context.

The current political and development paths in the world, specifically in some areas, including the Middle Eastern countries, are affected by conflicts, political instabilities, and power-based corruptions (www.transparency.org, 2019). While social-ecological systems in these countries have been severely damaged, their plans and programs are far from sustainable development thinking, collectively acting, trust-building, and resilience-building stewardship, which are some of the requirements to make a social-ecological system resilient. For example, the findings of the World Bank's research (El Khali, 2017), which looked at the Syrian conflict indicated that not only the physical infrastructures of the social-ecological systems had been destroyed but also "trust that binds people together” was damaged, which had a greater economic impact than the destruction of physical infrastructure. The Southeastern Anatolia Project in Turkey, which is called GAP (in Turkish: **G**üneydoğu **A**nadolu **P**rojesi), is another example. This large development project uses the water sources potential of Tigris and Euphrates, which affects negatively not only domestically but also regionally especially two immediate neighbors, Syria and Iraq, and consequently the other countries in the region including Iran (Dohrmann and Hatem, 2014). The other example is the drought that Iran has been experiencing for the last 20 years in which the regional conflicts, especially on its western and eastern borders, plays an essential role plus internal power-based corruptions and development approaches (Madani, 2014; Anbari et al., 2021; Pouladi, Afshar, Molajou and Afshar, 2019). This situation is what Chapin, Folke, and Kofinas (2009) left out of their resilience study and management focus because for them, as explicitly explained, it was hard to find some forms of substitution for those social, human, and natural capital that have been lost.

In addition, some research addressed contradictions between individuals’ interests and collective actions, which are required for common-pool management. For example, Ostrom et al. (1998) described how a community could be self-organized to use the common-pool resources while requiring a governing institutional evolution, among the other requirements. Also, there are studies that indicate how population’s characteristics are important in common-pool management. For example, the study by Naidu (2009) in India showed that heterogeneity of population with at least the characteristics of “wealth, identity, and interest” affected forests management in Himachal Pradesh. Referring to this real world it can be asked whether a social-ecological system could become resilient through self-organization and learning when institutions do not evolve or the management of institutions that engage in common-pool conflicts either each other or with communities.

The second type of conflict that requires more contextual-based experiments relates to self-organization and intervention through policies. As proposed by Folke, et al. (2002), the management of SESs is conditioned to be open to adapt and learn for building resilience. However, the proposed procedure of reorganizing in resilience management intended to be managed rather than to be formed through learning by individuals (Chapin, Folke and Kofinas, 2009). Therefore, it is a pragmatic question to ask whether a SES could autonomously become resilient through self-organization and learning. This question is especially valid in the conflictual context, which could be observed in one or a combination of the following situations: the management of organizations that conflict with each other; the management does not respond to and cannot shape human values as proposed by Chapin, Folke and Kofinas (2009); the management procedure is not open to adapt and learn as proposed by Folke et al. (2002); and resilience is not centered in the programs (Folke, 2002).

The third type of conflict relates to the institutional context. Matin and Taylor (2015) showed how institutionally an emerged resilient social-ecological system could enter to the “rigidity trap”, and become disabled in addressing the higher level integrated emerging ecological and social phenomena, such as “environmental degradation and social conflict”. This piece of finding is in the line of other institutional studies in social-ecological complex adaptive system (Young et al., 2006). For example, Vedwan and et al. (2007), whose thoughts were based on the water resource management in Florida, showed that "institutional evolution" was an "adaptive management" for the social-ecological systems with "unexpected changes" and uncertainty where the mechanistic natural resource management could not be effective. It has been argued that in an "inflexible and ineffective work-rule regime" the adaptability of organizations can be achieved through "permanent and latent rule-breaking" actions (Osrecki, 2015). Osrecki explains how anticorruption trends and activities, requesting "transparency, accountability, and compliance" could put the functional rule-breaking and adaptability to the risk in the bureaucratic formal systems. He supports his idea of functionality of organizational deviance theoretically as well as by showing how anticorruption movements, internationally and at the local levels, affect adaptability changes at micro structure. The paper by Osrecki (2015) can be considered a pathological study for strict rule-based formal organizations that are not able to adjust and adapt the complex systems, which complies with Simon's administrative approach (Simon, 1997).

In conflictual situation, not complying with the rules and regulations that stand against real life and the society's needs can be a supportive source from the people's activities in adjusting with the changes. For example, when the rank of Iran among all countries regarding rule of law is 24.04%, according to the Worldwide Governance Indicators Project of the World Bank Group (WGI-Interactive Data Access, 2020), the question can be raised whether people could benefit from higher rule of law, considering that laws generally are against people. From the institutional point of view for the SES, a conflict situation can differently affect organizational policymaking and implementation of the policies. One of the possibilities occurs when organizations are in conflict with the social-ecological resilience trend. If the personnel in the institutions have enough knowledge and capability of making changes they may play different roles from the organizational approaches and missions. In other words, conflict situation within and between organizations, where the monitoring becomes weakened, could provide an opportunity for service-providers/experts/authorities in the organizations to break rules and for individuals of population to reach out, cooperate, and learn, which may facilitate individuals' and groups' resilience-building and finally evolving the institutions. This, explains an automated way of institutional evolution through self-organization and learning when there is not any organizational intention and plan for resilience-building. This is a very well-known process of organizational capacity building. However, this optimistic process requires service-providers with the very strong knowledgeable and people-oriented personalities. Besides, the conflictual situation with the low monitoring system is multifaceted. Considering Iran's rank among all countries regarding corruption control, which is 14.9%, (WGI-Interactive Data Access, 2020), corruption, specially favoritism, which is a power mechanism of private use of public resources (Luo, 2005), can grow in this situation too. At the micro level in this situation, usually, corrupted personnel strongly develop groups, which are supported by the corrupted managers and corruption gradually grows within the organizations, which immediately affects people's lives. Still, as a hidden action, at the micro level, there is a possibility that the corrupted individuals at the certain level can be caught by the non-corrupted colleagues and if the organizations are not corrupted the non-corrupted managers can remove the corrupted personnel. This explains how management in SESs in conflict situations can be the dynamic result of all these unknown factors and requires more experiments.

CHAPTER THREE: THE BACKGROUND OF THE MOTIVATION CASE

This research is motived by Urmia Lake Basin (ULB) in Iran that has gone through drought process, and nationally and internationally, raised a wide range of concerns. After several years of politically denying and accepting the phenomenon of drying, finally, large variety of studies were carried out and several consultation workshops were held with the international engagement. Despite uncertainty for restorability of the lake, the nationwide program of Urmia Lake Restoration Program (ULRP) was designed and the implementation process started in 2014. As the ULB is a social-ecological complex adaptive system that had faced a drought, it is valuable to study the basin and the ULRP from the complexity perspective. For this reason, the ULRP from different aspects was systematically reviewed, and the process of changes in the ULB were monitored to find out whether the ULRP could be considered a proper program for the complexity of ULB. As it is discussed in this chapter, while the preliminary review of a number of studies that have been carried out for ULRP confirmed the acknowledgement of complexity of the ULB, a detail analysis of the ULRP indicated that it was a very conventional top-down strategic plan, which could not be considered a suitable planning for a complex system. To find the answer to the applicable question of how these studies led to a conventional plan, several studies were carried out from 2016 o 2019. Studying the methodology of planning of ULRP made it clear that a conventional land use method had applied, which was supported by a detail study of the agricultural land use methodology. This methodological study emphasizes that studying a complex system requires a different approach and method of studying in which both concepts and methods match. Furthermore, to understand whether a top-down policy of ULRP, which was based on a conventional method within the controlling management system, could effectively worked in a social-ecological system, one of the agricultural policies to legally restricting farmers' access to water to force them to change their crop patterns through establishing and using water-police forces was examined by applying a simulation modeling of ABM. Besides these detail studies, finally, the adaptability process of the ULB through ULRP was modeled to understand the probability of restoration of Urmia Lake through the ULRP. To read the result of applying the adaptability process, see Appendix II.

Some of the results of these studies are presented in this chapter as the lessons learnt from the background study of motivation case for this research. While the main concern of ULRP was to restore the lake and the main arguable subject was whether or not the lake was restorable, these studies revealed that not only the unity of the social-ecological system had been forgotten in ULRP but also, the system's resilience had not been studied. These studies showed that within a controlling top-down management system, even though the complexity of a SES was acknowledged, the suggested studies and plans followed the same path of top-down and controlling approach and methods. In addition, these studies suggested that the ULB required the resilience-building approach, if it intended to manage ULB as a complex adaptive system.

The contributions of studying ULB and ULRP from the complex adaptive system perspective to the current research are fundamental. First, the current research subject is based on the findings of studying ULB and ULRP, which indicates that resilience is a necessary subject that is forgotten in ULB studies. Second, concentrating on restoring ecological component of ULB by controlling people emphasized on the necessity of considering the unity of ecological and social components in the resilience-thinking study. Third, attempts to study ULB and restore it within a controlling top-down management system makes it important to understand how resilience of a SES changes and evolves under controlling management system in compare with resilience-building approach. Also, through field visits and informal interview, it was always heard that people believed they could have done better without such a controlling top-down management system that ordered them what to do and changed their orders daily because of the widespread conflicts among governmental organizations as well as the power-based corruption. Moreover, understanding the complexity of the social-ecological system through these studying of the ULB and ULRP contributed to conceptualize and develop an exploratory abstract ABM methodology for the current research. For example, the study of command and control of the policy of restricting farmers' access to water to force them to change their crop pattern showed that under the controlling management system, the system developed barriers for group working. In addition, while the controlling management system forced to achieve the predominant one target goal, which might somehow have reached that goal, the sustainability of the achievement not only could have been a major concern but also might accompany with several larger negative effects. The other type of lessons that is applied in this research is about how people believe and act together ignoring the governmental policies if they could. Or how service-providers within a different working organizational environment, in which a bottom-up is dominant, could effectively work and affect the life of people in compare with the command and control type of management system.

This chapter is about these studies and the lessons that are used in the current research to develop the exploratory abstract ABM to understand resilience mechanism under three types of institutional management system. Starting with a short description about the ULB and its background in Section 3.1, the ULRP's approach, methods, and management system are presented in Section 3.2. A short description of examining one of the policies of the ULRP, restricting farmers' access to water to force them to change crop pattern, is presented in Section 3.3. For full paper of this examination through ABM see the Appendix I. Also, the study of restoration of ULB through ULRP from the adaptability process perspective is presented in Appendix II.

3.1 Urmia Lake Basin Background

Urmia Lake, located in northwestern Iran, is one of the largest wetlands and has the biggest water volume in the country. In 1976, Urmia Lake is recognized as one of the largest hypersaline lakes in the world by UNESCO (ULRP, 2015)[1]. Urmia Lake Basin is about 51,876 Km^2, from which 67.7% is mountains, 17.5% is foothills and grasslands, and 14.8% is the lake area and swamp. The lake is a major water ecosystem, which had

[1]More information about the lake can be found on the website of the Urmia Lake Restoration Program: http://ulrp.sharif.ir/en/page/about-urmia-lake-basin

been losing water extremely rapidly, started 30 years ago. This had raised serious multi-dimensional ecological, social, economic, and even political concerns. However, Urmia Lake was not the only water ecosystem that was shrinking in Iran. It was a nationwide issue that wetlands and lakes face, such as Hammoon Lake in the east and Gavkhouni in south of the center. Therefore, Hardin's concept of the *Tragedy of the Commons* had found its way to the water sources management dialogues in Iran. Population growth, inefficient agricultural practices, and development are among the reasoned for today's water problems in Iran (Madani, 2014).

Figure 2. Location of Urmia Lake Basin among six main basins in Iran (map to the left) and the Lake's water area changes between 1984 (image in the middle) and 2012 (image to the right)
source: ULRP, 2015, c

According to ULRP and some of the published studies, it is declared that two natural and human factors have entwined to develop the current state of the lake. "A significant increase of irrigated farms", "unbalanced development in the agricultural sector", "construction of number dams", and "construction of the causeway" are the most effective human factors that can be accounted for the current lake state (ULRP, 2015 a)[2]. Alongside this information, the result of applying the Variable Infiltration Capacity model-based research (Shadkam, 2016) found that annual water inflow to Urmia Lake has decreased 48% over the period of 1960-2010. Aiming to understand the impacts of the climate change and the water resources development on the declining water inflow into Urmia Lake from 1960 to 2010, the research concludes "climate change is accounted for three fifths of water changes while the water resource development, which includes construction of water reservoirs and expansion of irrigated area, is the cause for the rest of the two fifths". This result is disproved by the study that Khatibi et al. (2020) carried out. They applied Inclusive Multiple Models (IMM) to test three hydrological close cases of Caspian Sea, Van Lake, and Urmia Lake. Comparing the data of three cases indicated while the Caspian Sea and Van Lake were hydrologically vibrant the 90% of Urmia Lake water volume had shrunk since 2000. They concluded that the climate change could not be accounted for the current state of Urmia Lake. They explained how changes in the ULB started in 1990 with two major projects of dam construction and expansion of pumpage programs. The operation of dams from 2000 caused the reduction of the flows into the lake because there was not any plan for compensation. According to this study, the management of the ULB had not accompanied with any conditions that was made by RAMSAR Convention for using the basin (https://www.ramsar.org/). This study

[2] Also, a detail information about the role of human and nature on the current situation of the lake can be found on the ULRP website, under the FAQ section in English in this link: http://ulrp.sharif.ir/en/faq-forum/what-were-main-reasons-emerging-current-critical-situation-urmia-lake

contradicts the ULRP's approach that accounts the human beings' activities dominantly accountable for the current situation of the lake instead of the policies and programs that have been made by the state.

Extensive ecological trend studies, including geology, hydrology, climate studies, and land use analysis, indicates Urmia Lake faces an emerging phenomenon of dying. According to the ULRP reports, the scientific studies indicate that over the past 30 years' renewable water resources in the Urmia Lake Basin has reduced by 20% while consumption has increased. Based on the ULRP estimation in 2015, the withdrawal rate of water in ULB is around 70%, while the UN permissible and secure rate is between 20% to 40% of renewable water resources (ULRP, 2015). This extra consumption has reduced the inflow of water to the lake. Generally, unsuitable water management accounts for most effective human factors for the state of the lake that is shrinking, especially for irrigated agriculture. Based on the 2006 National Census, the ULRP estimates that agricultural sector in the Basin consumes 60% of the renewable water sources and 90% of total water consumption in the Basin (ULRP, 2015).

Studies on land use changes in the Basin indicate that the area under irrigation cultivation has increased and the watershed area has decreased. For example, the allotment of irrigation lands has been changed from 300,000 acres to 500,000 from 1974 to 2014. Moreover, the crop types and farming practices have been changed from low-water demand (LWD) and dry farming, such as rainfed wheat, to high-water-demand (HWD) crops, such as sugar beet. Consequently, extracting extra water from surface and underground sources has been increased. In the ULB, over 40 years, from 1973 to 2013, the number of wells, legal and illegal, has increased from around 2,000 to more than 80,000. Out of a total population of 4,913553 in ULB, 1,523,201 persons live in rural area. However, the urban population directly or indirectly engages in agricultural activities (ULRP, 2015).

As many studies confirm[3], ULB is a complex adaptive system with all fundamental properties. The major emergence of drought phenomenon in Urmia Lake represents adaptability process as the fundamental property of the complex system, indicating that the resiliency of Urmia Lake Basin as a complex adaptive system is diminished. The drought process is the response of the lake's components to the disturbances that are imposed by both nature and human beings over a very long period of time. As the result of actions and interactions, the components of the lake have adapted themselves to the changing situation gradually. The intensity of the drought and changes in the lake's ecosystem, such as disappearing existing vegetation and replacing by the different types, has been a serious concern of the high possibility of the lake's transformation into a salt desert with a completely different ecosystem. It is reported that the lake has not been experienced such a draught over the past 200-thousand years (ULRP, 2015 a; Khatami, 2013). Even though the studies by the ULRP show that the Urmia Lake has kept its water level at the ecological threshold, some of the other studies claim that it had passed the ecological threshold for several years. For example, the study by Anbari et al. (2021) shows that the water level elevation of the lake in masl (meter above sea level) on the

[3] A wide range of studies can be found in the website of the Urmia Lake Restoration Program in English at this link: http://ulrp.sharif.ir/en/articles

fixed day of December 25 from 2001 to 2019 was lower than ecological level, as shown in Figure 3 . However, it is not clear whether it has passed its resilience threshold. Therefore, there is uncertainty about the possibility that UL could return to the previous state.

There had been several voices reflecting uncertainty in nor ability to restore the lake, among them late Parviz Kardavani's objection was outstanding. He claimed that there was no way to restore the lake, and it was better to accept it and prepare the situation for a desertification of the lake and make the changes less harmful[4]. Furthermore, in the report to the UNDP (2014) Wayne Wurtsbaugh from Utah State University, compares Urmia Lake with the Great Salt Lake and clarifies that Iran can "hope for the best (a wet cycle returns)" but they "should plan for the worst". In the same paper, Philip Micklin, from the Western Michigan University, compares UL with Aral Sea and concludes his report by encouraging Iran not to give up on a degraded water body because nature is resilient and with the proper effort and concern there is a possibility that Urmia Lake at least can be "partially restored" (UNDP, 2014). Moreover, there is not full agreement

[4] His thoughts can be found in some of the sources in Farsi, such as the following links:
http://hamshahrionline.ir/details/190458
http://www.jahannews.com/analysis/258451/%D8%AA%D9%8A%D8%B1-%D8%AE%D9%84%D8%A7%D8%B5-%D9%BE%D8%AF%D8%B1-%D9%83%D9%88%D9%8A%D8%B1-%D8%B4%D9%86%D8%A7%D8%B3%D9%8A-%D8%AF%D8%B1%D9%8A%D8%A7%DA%86%D9%87-%D8%A7%D8%B1%D9%88%D9%85%D9%8A%D9%87

among the local authorities[5] as well as local people[6], including farmers who are targeted to reduce their agricultural water consumptions to restore the lake.

Despite the uncertainty raised by several scholars, experts, and authorities on the possibility that Urmia Lake could return to the previous state, the study by Yazdandoost and Moradian (2016) simulated that the lake had the resilience capacity to return to its previous water level state. Decreasing allocated agricultural water use by 40% could regain part of the shrinking area. Not be included the social, political and economic challenges in the model, the results showed that even with 30% reduction water use in agricultural sector, the lake would regain its previous volume[7].

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[5] The speech by Dr. Kalantari, the head of the ULRP, in a local seminar around one and half years ago, in which he highlights the local authorities approach to the ULRP. It can be found in Farsi in this link: http://animal-informatics.com/_news/110/kalantari_strange_views.html

[6] The recent narrative study, which has not been published yet, indicates that some of the farmers in Hassanloo sub-basin do not believe that reducing consumption agricultural water by them can restore the lake.

[7] I have not been able to reach the model and find out what the exact elements are and how it works, however; I found out it is valuable to be mentioned as a very relevant research.

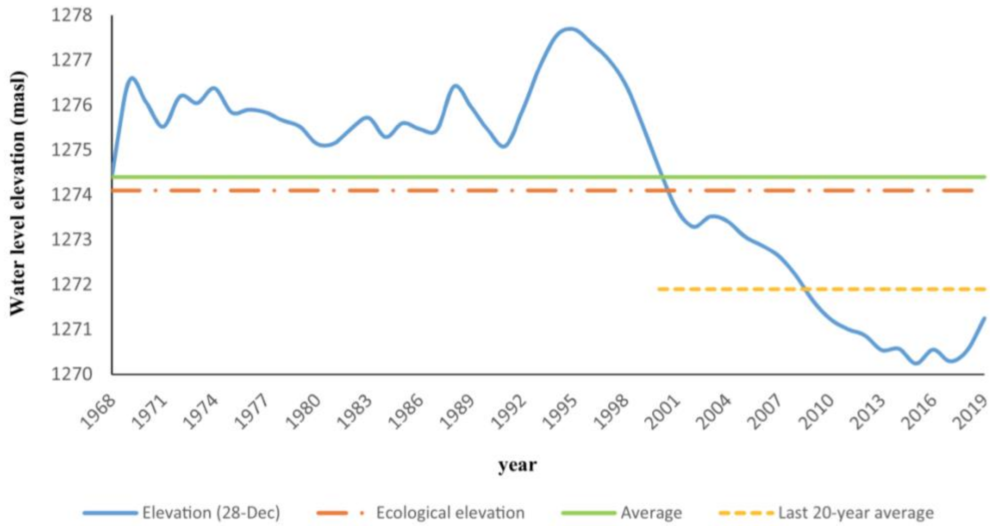

Figure 3. Changes of the Urmia Lake's water level (meter above sea level) over decades
Source: Anbari et al. (2021)

<u>3.2 The Urmia Lake Restoration Program: Approaches, Methods, and Management</u>

Acknowledging the complexity of ULB as a social-ecological system with all ecological, social, and economic impacts of its drying process and despite the uncertainty of the restorability capacity of the lake, there has been a consensus on the possibility to artificially restore the lake, which is concluded in the nationally managed Urmia Lake Restoration Program (ULRP, 2015 a). Even though the main question of whether the lake has passed the resilience threshold and whether it is able to get back to its previous state or at least to reorganize itself to function remains unanswered, the intention to artificially restore the lake complies with the concept of adaptability of the social-ecological complex system as identified by Walker, Holling, Carpenter, and Kinzig (2004).

The ULRP includes 6 packages and 27 large projects, through which water management in the agricultural sector is targeted to decrease water consumption by implementing different action plans at sub-basins of the ULB. The multidisciplinary studies at sub-basins of the ULRP are concluded in action plans with four strategies, including consumption and reduction water consumption management; water providing management; implementing the governance on water extraction and pick-up; and improving knowledge of consumer through advocacy and training. The strategy of governance on water extraction includes five action plans to control water extraction and implement laws for those extracting extra water without permission. The program mostly intends to establish the approach of Integrated Water Resource Management (IWRM) (Integrated Water Resources Management (IWRM) | International Decade for Action 'Water for Life' 2005-2015, 2021) in terms of institutional management of catchment and community involvement while the organizational system in the country, which is a top-down sectoral-based. A coordinating body is established at the highest national level to coordinate the sectoral national ministries and local organizations to ensure the program is implemented properly by the organizations which are in charge, such as Power ministry, Agricultural ministry and their local branches considering the existing conflict between these sectors for the water use. Moreover, it claims to draw the different stakeholders' engagement and local people participation.

The approach and method of planning and management in ULRP is conventional and cannot address the complexity of the Urmia Lake Basin, even though the complexity of ULB has been acknowledged by ULRP. The ULRP has been developed out of learning from the international experiences and built on top of very extensive multidisciplinary studies and constantly continues to research for any questions that it faces. Following

IWRM, it takes the multi-sector institutional water resources management approach by establishing the Urmia Lake Restoration Program National Committee (ULRPNC), which is a coordinating body for the ULB water resources at the highest national level (ULRP, 2015). It tries to move away from the dominant top-down central planning system in Iran by constantly referring to the local authorities, stakeholders, and people participation in all the ULRP mission and policies, which reflects that the ULRP authorities are well informed from the complexity of the ULB. However, reviewing the policies, reports, and studies that are carried out under the ULRP instruction reveals the following characteristics of their approaches:

- **Ignoring the unity of the social-ecological system of Urmia Lake**

  The ULRP separates the human and social subsystem from the ecological subsystem, which can be understood through all policies, reports and studies. Figure 4 reflects the approach of ULRP towards the Urmia Lake and its components. This photo is the cover of the 2015 report. As it indicates, the main target is saving the lake by supplying ecological water through reducing agriculture consumption, which needs people's participation. In other words, the approach is to target the lake's ecological life by using people's participation. The other elements of the picture indicate that the question of the restoration program is how to save the lake and make it resilient but not how to make the lake's social-ecological complex system a resilient system. This approach is dominant in all official documents[8] despite the ULRP having focused on

[8] The following paragraph from the mandate of the ULRP (p.14), also, indicates that Lake is the main goal and target not the social ecological of the Lake: "Seeking the participation of local

people's participation and their vulnerability and address people's livelihood, which are claimed that they have to be addressed. Still, the participation objective is to support vulnerable people in order to keep the Lake's ecological life safe.

In other words, with the intention of making a system ecologically resilient, policymakers apply the top-down policies of controlling communities through regulations. This is what the ULRP attempts to control people's activities and water consumption[9] in order to save the lake and build the lake's resiliency. It can be said that the ULRP's policy package is a double standard package: it picks resilience management approach for the lake but control management approach for people and social structures. This double standard behavior of the ULRP with the complex system roots in its approach to separate the ecology and social parts of the complex system.

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authorities in synchronization and synergy of actions considering achieving one goal "Rescue of Urmia Lake".

[9] It should be noted that the previous policies were about to control water, i.e. by dams, for socio economic development, which is criticized widely by the ULRP. Control policies in social-ecological complex system would lead to damaging the system both in ecological and social parts.

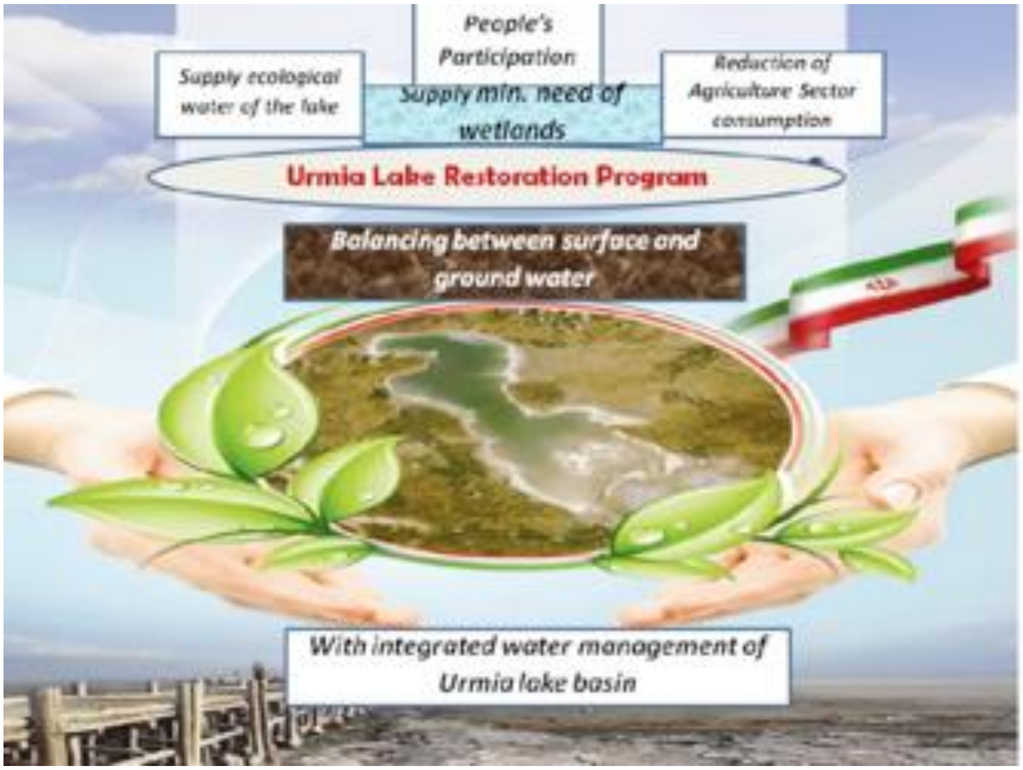

Figure 4. The ULRP approach: the cover of the ULRP report (2015)

- **Deterministic approach to the social-ecological complex system of Urmia Lake**

  The ULRP is very determined to save and rescue the Urmia Lake and strongly stands against the other approaches that question the possibility of saving the lake. One part of this deterministic approach is related to the ULRP's plans that are knowledge-based. The other part is for the situation that made the UL case become very politicized. The third part is about power-based economical corruption to use the UL resources. However, the deterministic approach is beyond these three realistic issues.

It relates to the deterministic behavior with the social-ecological complex system, believing that UL would respond to the projects as the ULRP has planned. For example, the ULRP develops mission and a 6-policy package, along with the timeline, presented in Figure 5. This timeline has not given any space to the possibility that the lake may not respond as the ULRP has planned. It should be noted, also, that in some cases, for example to divert rivers, the ULRP was quite flexible to change the plan and switched to the different options. Still, it is important to note how deterministically the ULRP approaches the UL case.

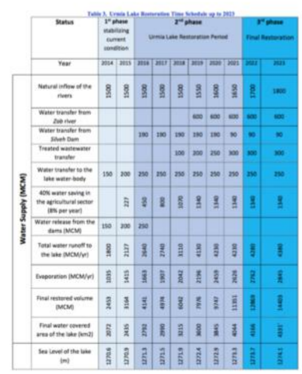

Table 3. Urmia Lake Restoration Time Schedule up to 2023

	Status	1st phase stabilizing current condition		2nd phase Urmia Lake Restoration Period						3rd phase Final Restoration	
	Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Water Supply (MCM)	Natural inflow of the rivers	1500	1500	1500	1500	1500	1550	1600	1650	1700	1800
	Water transfer from Zab river						600	600	600	600	600
	Water transfer from Silveh Dam			190	190	190	190	190	90	90	90
	Treated wastewater transfer					100	200	250	300	300	300
	Water transfer to the lake water-body	150	200	250	250	250	250	250	250	250	250
	40% water saving in the agricultural sector (8% per year)		227	450	800	1070	1340	1340	1340	1340	1340
	Water release from the dams (MCM)	150	200	250							
	Total water runoff to the lake (MCM/yr)	1800	2127	2640	2740	3110	4130	4230	4230	4280	4380
	Evaporation (MCM/yr)	1035	1415	1663	1907	2042	2196	2459	2626	2762	2845
	Final restored volume (MCM)	2459	3164	4141	4974	6042	7876	9747	11351	12869	14403
	Final water covered area of the lake (km2)	2072	2435	2792	2990	3215	3600	3845	4044	4166	4337
	Sea Level of the lake (m)	1270.6	1270.9	1271.3	1271.5	1271.9	1272.4	1272.9	1273.3	1273.7	1274.1

Figure 5. The ULRP proposed plan with the activities and timeline for one of the packages (ULRP, 2015)

- **Approaching the emergent phenomenon of drying up as a crisis rather than the inherence capacity of the Urmia Lake's social-ecological complex system**

  The ULRP considers the current state of the UL as an emergent crisis not as an inherent part of the Urmia Lake's complex system. In all the written documents and reports the lake's state is called the crisis of UL. The example is the published *Brief Report and Projects Outlines* (ULRP, 2015). It reflects the understanding of the ULRP of the UL system, which complies with the other two aforementioned approaches. The crisis is justified by separating the social and ecological parts of the system based on believing that the ecological part of the lake is at the crisis state because of the human use of water and land resources in ULB. It should be noted that based on the concepts that are identified in this dissertation, the unsustainable use of water and land by people also, have to be considered as the adaptive behavior of human being part of the social-ecological complex system. Moreover, it should be approached in the same way when it comes to the activities of the people, including managers and local people, to help the lake to get back to its function. This is the other adaptive behavior that is taken by the human being part of the system if the unity of system can be understood.

- **Conventional approach in pragmatic studies for intervention**: **Targeting one variable with its linearity and predictability method**

  The ULRP targets one variable of rescuing Urmia Lake in its pragmatic studies[10], which leads to apply linearity and predictability conventional method in studying and planning. In its method of planning, ULRP identifies how much water has to be released to UL and how much water has to be limited for consumption especially in

[10] Targeting one variable is not just the approach of the ULRP in its studies, it is the main part of all actions and decisions that there is only one goal. For example, in the mandate of the ULRP (ULRP, 2015, p.14), this is highlighted in one of the mandates as follows: "Seeking the participation of local authorities in synchronization and synergy of actions considering achieving one goal "Rescue of Urmia Lake".

agricultural sector for the period of the proposed plans. Then, the pragmatic studies, which are massive and multidisciplinary[11], follow the plans and especially in the economic section, the proposed plans are evaluated linearly and predicted what the situation of agriculture will be over this period of time. For example, they identify how much lands have to be allocated to what types of crops, how much labor forces have to be engaged and what the income of farmers would be. Following this step, the social studies, for example, measure whether or not farmers would follow the plans and under what conditions. Then, the proposed projects in each section are synthesized and became ready for implementing. What really is missing here is to understand that any intervention in each part of the system and any decision would affect the entire system and the year after the first project is introduced the system will be different because of the action and interactions among the parts of the system, both socially and ecologically[12].

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[11] The Urmia Lake Basin is divided to several sub-basins and zones and a comprehensive study are conducted in each of them for planning. The following is the a comprehensive report in ten volumes plus the synthesis volume for sub-basin of Miandooub (translated to English) , aiming at developing projects according to the road map (The reports are provided by the ULRP, 2016). Volume of Synthesis of Finding and proposed plans and projects; 1) Agricultural sector and proposed plans: 2) Farming system and social characteristics: 3) Economic studies: 4) River engineering; 5) Water situation and plans to improve irrigation; 6) Water resource and consumption planning and management; 7) Underground water; 8) Feasible study to identify farms to improve the farming system; 9) Participation, Extension, Education; 10) Rules and Regulations.

[12] It is reported that in a small area farmers had been asked to reduce the sugar beet area to 23 ha from 38, for some years it came down, and again last year it went up to 31 ha. This is part of a local governors interview in Farsi, which is available on 12/15/2016 at https://www.tasnimnews.com/fa/news/1395/06/13/1177325/%D9%85%D8%B3%D8%A6%D9%84%D9%87-%D8%A7%D8%AD%DB%8C%D8%A7%DB%8C-%D8%AF%D8%B1%DB%8C%D8%A7%DA%86%D9%87-%D8%A7%D8%B1%D9%88%D9%85%DB%8C%D9%87-%D8%A7%D8%B2-%D8%A7%DB%8C%D8%B1%D8%A7%D9%86-%D9%81%D8%B1%D8%A7%D8%AA%D8%B1-%D8%B1%D9%81%D8%AA%D9%87-%D8%A7%D8%B3%D8%AA

One of the very important techniques that can be applied in uncertainty, which is not linearity approach, is to capture the adaptive decision making process by people, instead of predicting based on targeting one variable. Understanding this adaptive decision making process would help for a better understanding of the future[13]. This targeting one variable in uncertain situation is supported by reviewing the agricultural land use planning method that is applied by ULRP.

Understanding the land-use method and modeling in the ULB, the ULPR's documents, reports, studies, surveys, and the road maps are reviewed. The sources of information are two types. First, The ULRP road map, strategies, and studies at national level. Second, the comprehensive studies at Sub-basin levels that were carried out by consulting firms. ULB include 7 Sub-basins and each of them has studied by one of the consulting firm. The results of studies for each Sub-basin published in 10 volumes, as the followings:

- Volume One: Synthesizing of the Sub-basin Studies, Strategies and Action Plan Alternatives;
- Volume Two: Agricultural Current Situation and Suggested Programs;
- Volume Three: Social Characteristics and Farming System,
- Volume Four: Economical Studies.
- Volume Five: River Engineering;

[13] Brian Walker and his colleagues (Walker, et al., 2002) comments for the situation that conventional decision analysis under the uncertainty cannot hold, to apply the resilience analysis with its six assumptions, which could help to find the resilience pathways in a collaborative way.

- Volume Six: Irrigating Current Situation and Improving Plan;
- Volume Seven: Planning and Water Resource and Consumption Management;
- Volume Eight: Assessing the Possibilities and Identifying Pilot Farms;
- Volume Nine: Advocacy, Training, and Planning to Locate Social Participation Camps; and
- Volume Ten: Legal consideration and Rules and Regulations.

Figure 6 presents the summary of this review in a format of diagram.

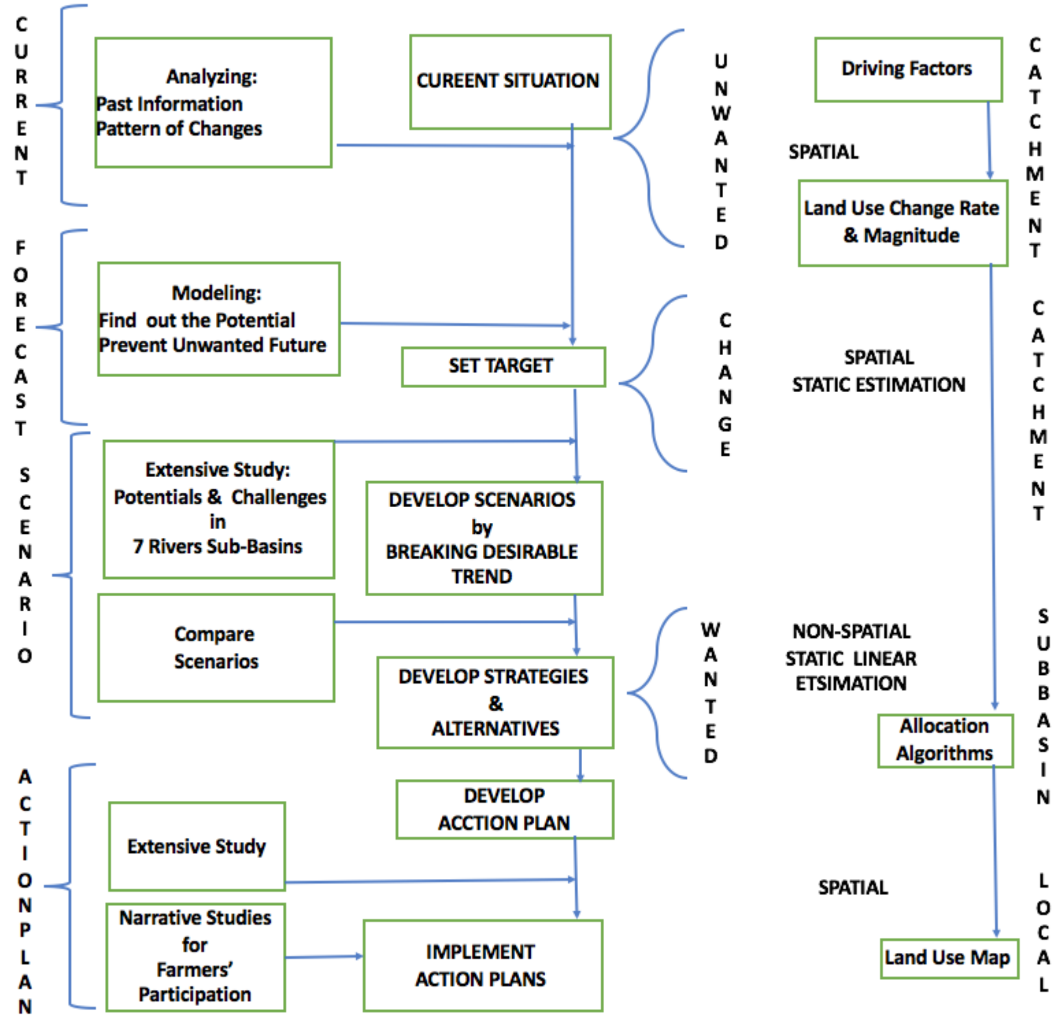

Figure 6.Tthe applied land use model by Urmia Lake Restoration Program(ULRP)

The process for land-use planning starts from the unwanted *current situation* at the catchment level, which shows that the lake is going through a dying process. In order to identify the driving forces, an extensive multidisciplinary historical study at the catchment level is carried out, including geology, hydrology, climate, and land use. Reviewing the patterns of changes, such as decreasing the amount of water, which flows into the lake, or increasing the agricultural lands and irrigation crops, indicate the human development role in current unwanted situation[14]. Estimation at catchment level indicates that major water consumption, around 90%, belongs to agricultural sector, which has the capacity to be reduced as much as 40%.

Possible solutions to divert the path toward the *unwanted future* are searched in a combination comparative of historical information and estimation of possible potential of water sources at catchment level. Table 1 shows how the potential sources are recognized in order to change the path to unwanted future. Moreover, it shows that the *target* for agricultural sector is set at the level of reducing 40% water use from two sources of surface and ground water, and consequently in a developed time schedule to restore the lake, it is mentioned that in five years, the agricultural water use has to be reduced 8% annually[15] and in total 40% (ULRP, 2015, pp 21-24). Moreover, the agricultural target has to be included increasing the agricultural productivity for the 60% remained water-use in the agricultural sector (ULRP, 2015).

However, when agricultural sector is targeted, simultaneously some modeling present that there is a potential of reducing 40% water to save the lake. The modeling by Yazdandoost and Moradian (2016), is one of the example of modeling that was presented earlier.

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[14] Some of the maps and diagrams, which represent patterns of changes are attached.

[15] The annual rate is not mentioned consistently. In the Urmia Lake Recovery Report, printed in October 2015, in page 23 it is mentioned that "Decreasing the agricultural water consumption trend from 8% to 10% per year" while in the report's page 22 it is mentioned, "40% water saving in the agricultural sector (8% per year)." But, the total 40% is completely consistent.

Table 1. Water Supply Potential for Urmia Lake during ULRP

Water Source	Description		Annual Volume of Water Transfer To Lake (MCM)
Current Volume of Water Transfer to the Lake from Rivers	Net Water Inflow Volume to the Lake's Water Body		1500
Water Resources Outside Basin	Water Transfer Project from Zab River		600
	Water Transfer Project from Lavin River (Silveh Dam)		5th 190 3th 90
Unconventional Water Resources	Basin Seepage		300
Reducing the Water Consumption in Agricultural Sector	Savings in Agricultural Water Use (40%)	From Surface Water Resources	970
		From Ground Water Resources	370
	Releasing Water Storage of Dams		Year One: 150 Year Two: 200 Year Three: 250
Reducing the Water Loss in the Lake's Buffer Zone	Water Transfer to Lake's Body of Water		250

Source: (ULRP, 2015)

Based on the target for agricultural sector, two main strategies for agriculture are developed at the catchment level, which are to "control and reduce water use in agricultural sector". Several projects with specified areas, budget and responsible organizations are developed. They are mainly to "design and implement the pressurized sprinkler-irrigation", "design and implement the pipeline water transfer, design and implement the sub-main irrigation and drainage network", "study and production of less water consumption varieties of seeds", "modify the water allocation licenses from ground and surface water for users ", and "study on implementing the strategy to reduce 40% of water usage in agricultural sector, which is approved by the Cabinet" (ULRP, pp 34-35). Then, the extensive studies at the sub-basins are carried out in order to identify policies and plans to the target of 40% reduction water consumption in agricultural sector in five years, setting the goal of 8% reduction of water consumption each year[16] (IMOF, 2016). The studies have the spatial characteristics and estimation nature. These are the steps of the applied method:

1. Each sub-basin is zoned based on the hydrological criteria, including access to surface and ground water, irrigation facilities, developed units of irrigation and drainage network, just mentioned a few.

2. Agricultural land-uses are estimated based on satellite images, controlled information with the information in the field, and water sources and water consumptions as well as historical information. For example, in Miandoaab, one of the sub-basin, the types of agricultural land-uses are estimated and presented in a table based on 21 identified zones, showing how many acres and of which lands are allocated to which types of agricultural activities, such as irrigation, horticulture, wood trees, trees around rivers, and the others.

3. Agriculture's current situation study is one of the several items of current situation studies, including trends of social changes and agricultural development, and population characteristics, and the current water sources systems. This study includes different types of agricultural land uses, crop patterns, presented in areas of each crop type and its portion in the crop patterns, yield of each crop type and the prevalence of agricultural practices. To identify the agricultural land uses in the river beds, a combination of previous studies and field visits is applied. To identify the land uses in the areas, except river beds, which are using surface and ground water sources, several steps have been

[16] The studies at all sub-basins are the same and one can find it for example in the first volume out of a 10- volume reports for Miandoaab sub-basin studies

taken. First, the satellite images are interpreted and synthesized with the information from the filed surveys. To Identify crop patterns, estimate yields, and understand the applied technologies, field visits and questionnaires are used. Then, for synthesizing the information and adjusting them, the local experts' knowledges and the information that is produced by Iran Statistic Center (ISC) are used.

4. Agricultural economy is estimated for the sub-basins as well as for major crops. By estimating the average efficiency of current water-use of different crops and the average potential efficiency water-use, the value added for each crop is estimated and value added of different crops are compared and discussed. The same method is applied for discussion of labor-forces and the value added of labor for different crops are compared and discussed.

Specifically, the agricultural economy is estimated under each of the four scenarios and compared the quantitative results, in terms of area for each crop patterns, water use, income, and labor requirements. Scenarios, which are developed at the catchment level, have an accumulative nature, which means the second scenario is the first one plus a new activity.

These are the scenarios:

1. Increasing water efficiency use,
2. Increasing water efficiency use + managing river beds
3. Increasing water efficiency use + managing river beds + changing crop patterns
4. Increasing water efficiency use + managing river beds + changing crop patterns + applying less access to water for crops (MOP, 2016, volume 3, p. 21).

5. Action plans, 20 actions with their sub-activities, budget and time schedule, are introduced under four following strategies at the sub-basins:

   Strategy 1: Managing Water Supply;

   Strategy 2: Managing Water Demand and Reducing Water Consumption;

   Strategy 3: Law Enforcement for Illegal Water Extraction; and

   Strategy 4: Improving Farmers' Knowledge through Extension and Training

6. Carrying out some studies at local level for implementing action plans, including encouraging farmers to change their crop pattern. The first action plan is to provide cadaster maps in order to identify the boundaries for activities.

Summarizing the general method, the driving forces and land-use changes rate and magnitude are identified at the catchment level with historical spatial information and static estimation, which leads to allocation algorithms at the sub-basins and finally land use maps are produced at local level for implementing the action plans. Therefore, there is no information available at "micro level conditions and constrains; driving factors of land-use change" and "micro level decision making" by multi agents (Verburg et al., 2004).

It can be concluded that some characteristics in the applied method of land-use and scenario development concept and procedure constitute a top-down static land-use approach. The driving forces of land-use changes are identified based on analyzing the historical trend at the catchment level without applying multi-level and cross scaling analyzing. For changing an unwanted forecasted future to desirable situation, the water-sources potential is recognized at the catchment level and modeled based on forecasting inflow-outflow water, ignoring the social-ecological capacity of the system. The land-use's target is set at the catchment level based on the same data and forecast of desirable future, which is estimated based on static algorithms. Using static method of predicting of land-use change in future, as Verburg et al. (2004) argue, cannot capture the "feedbacks and path dependencies", which is required for a dynamic system. In ULB, for example, the feedback of changing crops policy, which may affect to change the other crops in the farms and in turn would affect the targeted crops, or market feedback to the targeted crops for changes and consequently their impacts on the following decisions to change the crop pattern by farmers in the path have not been seen in this static estimation and land-use algorithms. Moreover, the direct land-users and their decision-making mechanisms for their land-uses are totally ignored at this level. Therefore, in estimating changing land-uses statically at the catchment level, the micro-level interactions, either crops or land-users, have not been taken into account. The dynamic actions and interactions among the parts at micro-level of social-ecological system are the determining factors of real land-use changes that have to be considered in predicting land-use changes in future. This is one of the reasons that agent-based modeling, especially multi-agent system, can be used to capture the feedbacks and path dependence changing of land-use while individual farmers decide to change and are affected by changes in the environment toward a desirable target.

As a social ecological complex system, the applied land use method in ULB doesn't capture and reflect the complexity. As a complex system, Urmia lake is diverse in terms of spatial and temporal for land use. Moreover, land users are heterogeneous and the mechanism of land use decision-making for their lands are not known. The survey study on farming system and social characteristics is about to understand how to implement the plans to achieve the goal of 40% reduction in water-use. The study is presented as an aggregated information at sub-basin and cannot capture the complexity of decision making for land use by land users. As a complex system, any macro-level change has to be understood through actions and interactions with environment at micro-level and with the system at macro-level. The applied land use method doesn't capture changes from within the complex system. Applied land use plan is based on a linear estimation and a one-dimensional optimizing of top-down land use, which cannot reflect multidimensionality of the complexity of a social ecological system and cannot develop diverse scenarios. Scenarios are just breaking a trend toward the target.

- **Top-down Approach to local and people participation in the ULRP**

  The authors of ULRP understand the value of stakeholders' engagements very well. They also know that without participation of people and local authorities the goal to "rescue the Urmia Lake" is not reachable. From the first steps that ULPR was launched, this was reflected in all the reports and documents that were published. In a very top-down planning system in Iran, acknowledging the participation of people and local authorities is very valuable. This could be promoted as the result of combination of the followings: international community engagement in the program; devoted to the integrated water resource management and sustainability; and the sensitivity of the local people to the process of drying up the lake for more than 10 years. People and communities in the ULB had been actively advocating to save the lake, but they had been treated badly by the then administration, and they feel strong ownership to the lake and they expect to be engaged in any restoration program. The ULRP not only highlights the people's participation in the ULRP but also it is formally reported that the local Non-Governmental Organizations (NGOs) have been involved in the ULRP process. Also, it is acknowledged by the head of the ULRP that the first phase of the program could not have been successfully implemented without the strong participation and volunteers that the ULRP received in the first phase. However, these claims need to be verified in the field because they had not been supported by the local communities in the informal field visits and interviews in 2019.

Moreover, in last 40 years, the centralized planning always has been criticized for not being able to achieve to its goal, specifically in every 5-year plan. In the agricultural sector, always agricultural advocates had been criticized for not visiting the fields and transferring the new knowledge or encouraging farmers to follow the guidelines. To understand how this centralized system works at local level, in 2017, a Modern Agricultural Knowledge-based Advocacy Plan was introduced. The head of the Agricultural Research, Education, and Advocacy, Skandar Zan, in the First National Seminar of Local Service-Centers, announced this plan, and explained that renovation and equipment service-centers and mapping areas for allocating to advocators as the organizational objectives of the plan. Providing car, so that advocator could visit the field (The Knowledge-based Modern Agricultural Advocacy Plan Is Ready, 2017). This proposal to change the advocacy system explains the observations of the crowded service-centers, in which farmers are looking for some experts to support them and rarely receive. Kazem Khavazi, the Head of Public Relation of Agriculture Department in Khorasan Jonoubi Province in the meeting with the agricultural advocators in Birjand said that previously the state spent a lot of budget to contact with farmers but the objectives had not been met. He mentioned that previously there was an advocator per 3500 farmers, but in the new plan it had reduced to an advocator per 600 farmers (Implementing the Agricultural Modern Advocacy Developed Two Way Relationship Between the State and Farmers, 2018).

According to the ULRP's 6-policy plan and the other documents, the ULRP considers people as a valuable force to implement what is planned for them[17]. Also, some of the research indicate that people do not agree with some of the policies in programs, including crop type changes. The ULRP authorities believe that if people get more information and become aware of the value of the policies they will comply[18]. The ULRP intends to draw farmers' trust and addresses their uncertainty about the authorities' determination to implement the action plan.

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[17] This approach is very well documented by the ULRP when it highlights the "local communities' participations" as one of the program's challenges. ".. contribution of all stakeholder particularly local residents is an essential parameter supporting implementation o Urmia Lake rescue program successful." It is expected from all stakeholders especially agricultural sector not only to participate effectively in implementation of programs but also to cooperate completely on decreasing the volume of agricultural water consumption and supplying the lake water rights." (ULRP, 2015, p.18).

[18] For example, two of the mandate of the ULRP, which are reflected here, do not have any aspect except making people concern about the lake to cooperate with the program: "Making efforts to the public participation to restore and improve the present situation of the Lake through public awareness and changing Urmia Lake crisis to a "public concern". Attempting to create the public and comprehensive determination and participation through informative mass media to restore

Still, this type of participation of people, which engages people to implement the programs not in the decision-making process, is a top-down approach to the participation. Dealing with a complex social-ecological system people have to be integral part of the any decisions, and top down approach cannot fulfil the objective of managing the system. In the bottom-up participatory approach people involves in the process of any decision, implementing and revising the plans, through which people get empowered and resilient as a one system. The participation approach in the ULRP is far from building a resilient community. Interestingly, the ULRP claims that farmers are beneficiaries, while they need to be agents to manage their social-ecological complex system. For better understanding of the differences between these two approaches, they are abstractly demonstrated in the Figure 7.

Urmia Lake, to improve its present condition and to observe it as “a public challenge” (ULRP, 2015, p.14).

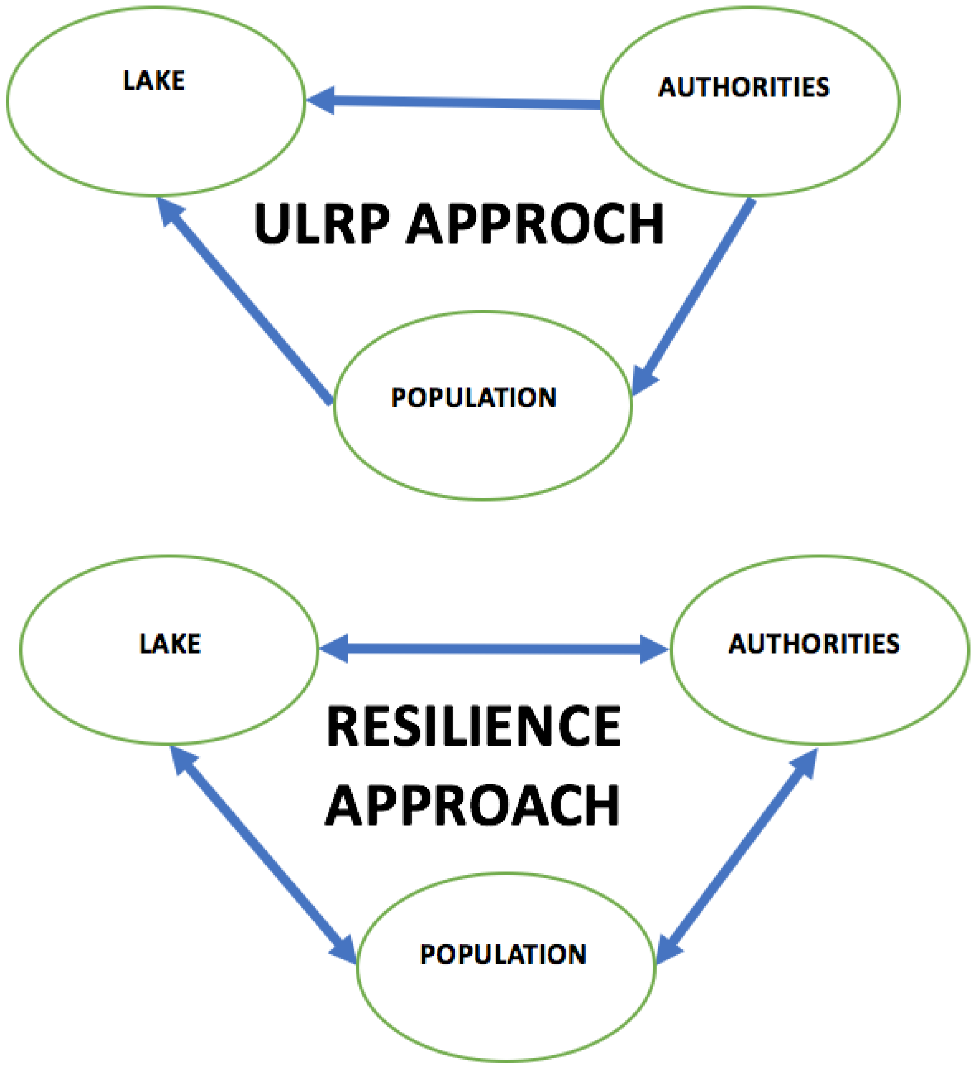

Figure 7. Participation approaches in ULRP and the resilience management

- **Control approach in managing the social-ecological complex system:**

The ULRP control management approach can be captured by reviewing its 6-policy package, which can be read as follows:

1. **Control** and reduction of water consumption in agricultural sector;
2. **Control** and reduction withdrawal of surface and groundwater resources;

3. Initiatives on production and mitigation of negative impacts;
4. Studies and software measures;
5. Facilitate and increase of the water volume entering to the lake throughout structural measures; and
6. Water supply from new water resources.

In other words, with the intention of making a system ecologically resilient, policymakers apply the top-down policies of controlling communities through regulations. This is what the ULRP attempts to control people's activities and water consumption[19] in order to save the Lake and build the lake resilient. That is, the ULRP's policies package is a double standard package: it picks the ecological resilience management approach for the Lake but control management approach for people and social structures. This double standard behavior of the ULRP with the complex system roots in its approach to separate the ecology and social parts of the complex system.

3.3 Examining the Policy of Legally Restricting Farmers' Access to Water, Forcing Crop Pattern Change

To reduce water consumption in the Basin, the ULRP widely targets the agricultural sector and proposes the project of changing crop patterns from high-water-demand (HWD) to low-water-demand (LWD), which includes a component to control water consumption by establishing water-police forces. To explore how these policies may

[19] It should be noted that the previous policies were about to control water, i.e. by dams, for socio economic development, which is criticized widely by the ULRP. Control policies in social-ecological complex system would lead to damaging the system both in ecological and social parts.

work and understand whether the ecological goal can be achieved via command and control polices in ULB, a simulation model of Agent-Based Modeling was applied (see Attachment I for full paper and description of the model).

As explained in Section 3.1, the ULRP's calculation shows that a 40% -water consumption reduction in agricultural sector is necessary for restoration of the lake (ULRP, 2015; Yazdandoost and Moradian, 2016). Some of the strategies that are proposed by ULRP to achieve the goal of reducing water consumption in agricultural sector include increasing water efficiency in farming practices and changing crop types from high water-demand (HWD) to low water-demand (LWD) or leaving farmlands uncultivated. The studies as well as the first attempts of changing crop patterns, such as unsuccessful negotiation with farmers to leave their farmlands uncultivated, add the attainability of the reduction of water consumption in the agricultural sector to the unanswered questions, including the restorability of the lake. To change crop patterns from HWD to LWD as one of the commanding policies, a controlling system is proposed, which includes limiting farmers' access to water, modifying laws, and establishing law enforcement of water-police forces to control farmers' water consumption by enforcing the law. However, changing the crop patterns is one of the most challenging policy that ULRP faces. Based on the studies and generally, while high water-demand (HWD) crops consume several times water for low water-demand (LWD) types, they require much more labor, which farmers' family members can engage on, and produce much more income. The example is sugar beet that is suggested to be replaced by rapeseed.

In addition, the wide range of multidisciplinary studies, which were carried out in 2017, as well as the data from the historical studies indicated that farmers not only resist to change their crop patterns but also extract water in any way, even illegally, to fulfill their farming needs. For example, in an unpublished narrative study that was carried out by the ULRP, farmers refused to accept the ULRP's strategy to change their crop types and suggested that the ULRP had to return those water sources to the Basin that had been diverted to the other areas as well as issuing permission to farmers to dig deeper wells. The farmers' opinion to the reason of the lake's drought and its relation to the farming activities could be another element that affects farmers' decisions for not changing their crops from HWD to LWD types[20]. They also expressed that they do not leave their lands nor do accept the other options of agricultural-related job opportunities, because farming is their jobs. Therefore, limiting access to water is one of the policies through which the developers of ULRP is hoping to force farmers to change their crop patters from HWD to LWD crops.

Concerning water use monitoring systems, a new law enforcement establishment is introduced as the police forces specifically to control water extraction by farmers in order to implement restricted farmers' access to water and subsequently fostering the program of changing crop patterns (IMOE, 1st volume, 2016)**.** This control system has a legal component as well. According to the existing law, law enforcement can fill the

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[20] According to the narrative studies, which is carried out in Hasanloo sub-basin, some of the farmers believe that draught is a periodic natural phenomenon. Other farmers believe that the draught is the result of government policy to divert rivers. Not all farmers believe that reducing water consumption by changing crop would restore the lake (unpublished narrative studies by ULRP).

unpermitted wells only by the order of a court. Moreover, the law enforcement officials cannot prevent farmers' access to the surface water except in the agriculturally developed areas[21]. The ULRP advocates to revise the water related laws in order to control water consumption more easily, still the content is not known.

Narrative reports indicate that farmers' decisions on crop pattern do not follow the allocated amount of water to the farmlands. In the case of limiting farmers' access to water, several factors are involved in crop decisions, ranging from farmers' economic situation to their ability to extract and pick up water illegally. Still, searching and extracting extra water by farmers is an option that can be materialized based on farmers' status and behaviors, and whether they are supported by other farmers. Farmers' decisions for illegally seeking and extracting water are affected by their relationships with law enforcement officials as well. In many cases, law enforcement officials ignore farmers seeking extra water or having illegal wells for several reasons. Moreover, the location of farmlands can affect farmers' decisions to seek extra-water as well. For example, if their lands are not too far from the surface water sources, which have not been dried, they may get extra water. In addition, if farmers are forced to leave their lands uncultivated, there are people ready to rent their lands for farming.

Applying the simulation model of ABM for analyzing the policy of water-police shows that monitoring and controlling water consumption by the water-police in the model immediately affects the crop patterns. The amount of farmland with HWD crops

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[21] Avoiding any decision or action that causes social and political tension is one of the reasons that keeps the government to implement the laws regarding the illegal wells. (IMOE, 1st volume, Farsi, 2016, p. 2.43)

decreases and the farmland with LWD crop increases, but, it does not stabilize for a long time. Moreover, the HWD crops never disappear from the crop pattern, but the farmlands change to the battle fields between farmers and water-police. The other outputs of the model are the increasing dissatisfaction and the decreasing farmers' income, which indicates how the approach of command and control can produce dissatisfaction and poverty. Besides questioning the feasibility of building water-police-stations and keeping so many water-police personnel functional, the other outputs except crop changes should be taken into consideration for decision making.

In summary, the findings under different strategies indicate that targeting crop patterns change by legally limiting farmers' access to water may force farmers to change their crop patterns for a short period of time as long as the number of police constantly increases. However, it is not a sustainable policy for either changing the crop patterns nor restoring the lake. This result is approved by another simulation model using Agent-Based Model (ABM) in combination with Artificial Neural Network (ANN) by a group of scholars from Tabriz University (Anbari, Zarghami and Nadiri, 2021) to explore the impact of three projects of ULRP on the underground water and farmers' income in Shabestar-Sofian Plain (SSP) in Urmia Lake Basin (ULB). The projects are Wells Monitoring Project (WMP), License Adjustment Certification (LAC), and Promoting Modern Irrigation Technology (PMIT). The results of the simulation indicated that two projects of WMP and LAC, that are about controlling, increased the groundwater but tremendously reduced farmers' income. The PMIT would increase farmers' income but decreased groundwater.

CHAPTER FOUR: METHODOLOGY

Methodological challenge in resilience studies is one of the main issues that this research attempts to address. As explained in Chapter One and the research hypothesis, this research applies Agent –Based Modeling (ABM) as a simulation because it complies with the integrated bottom-up approach of the resilience study in SESs. ABM facilitates applying the integrated approach of the study by capturing the dynamics within the integrated SESs without requiring any synthesizing the results of at least two social and ecological subsystems. The integrated dynamic starts at the lowest level of individuals of social and ecological components, the dynamic between parts, subsystems, and the system continues, and the properties of individuals, components, and system evolves. ABM enables the research to capture this nested dynamic. It, also, complies with the bottom-up approach and provides an experimental platform to study resilience changes at multi levels instead of just emerging system level, because the research hypothesizes that resilience is the capacities of individuals' as well as the system level of SES. Moreover, ABM simulation enables a scientific opportunity to study beyond specific cases by developing an abstract virtual world.

Choosing ABM for this research has two objectives. First, as the research method the objective is to explore the resilience status of a social-ecological systems (SESs) to answer the question of what the resilience status of a SES, which is specified in ULB, is and how it changes through self-organization and learning within the political conflictual context. Second, as the methodological concern, the objective is to understand how far ABM is applicable in resilience studies within the integrated bottom-up approach. To achieve these two methodological objectives, the model, which is called MY-VIRTUAL-ULB, is conceptualized based on the learning from literatures and background case study of Urmia Lake Basin. Then, the model is developed and programed, and finally, the data is analyzed and verified. To make the model scientifically understandable and replicable, the report of conceptualizing and programing are presented in the ODD + D format (Müller et al., 2013), which is an extension of the ODD (Overview, Design Concepts, and Details) protocol (Grimm et al., 2006) for describing human decisions in ABMs. Originated in ecology, ODD is a standard framework with a checklist of guiding questions for describing ABMs. Critically revising ODD to include human decision-making, Müller et al. (2013) develop the ODD +D framework, in which three main elements of "Theoretical and Empirical Background", "Individual Decision-Making", and "Heterogeneity" are added to the Design Concepts, and the main element of the "Implementation Details" is added to the structural Details elements. The model is programed and executed in NetLogo 5.3.1. (Rand and Wilensky, 2016).

Following the ODD + D protocol (Müller et al., 2013), this chapter includes three sections. Focusing on the research and model purpose, in Section 4.1, the model entities, variables, and attributes, as well as process are reviewed. In Section 4.2, with regard to the theoretical and empirical background of the applied ABM in resilience field of SESs, the diverse aspects of applied concepts to design the model are explained, which covers individual decision-making, learning, sensing, prediction, interactions, collectives, heterogeneity, stochasticity, and observation. In Section 4.3, the details for programing the model in NetLogo 5.3.1 are described, which includes four subsections of implementation details, initialization, input data, and sub-models. MY-VIRTUAL-ULB can be reached here. The Pseudocode is attached, as APPENDIX III.

4.1 Model Overview

4.1.1 Purpose

The purpose of the model is to explore the bottom-up resilience enhancement in Urmia Lake Basin social-ecological system through self-organization and learning of adaptive process under different types of governmental and institutional management, including, but not limited to, Controlling Management (CM), Resilience–building (RB), and No-management (NM), as a base-line, where none of the controlling and resilience-building procedures are applied. The model mainly addresses researchers as well as policy-makers in the resilience field.

4.1.2 Entities, State Variables, and Scales

The world of this model is virtual and the space is an artificial grid with a total number of 1090 land units consists of productive (1058 units) and non-productive, three types of space-related agents, which are land-owner, natural-connector, and service-provider/manger, and links of land units through natural-connector agent. As explained in Section 3.2 and Section 4.1.3, the model performs in an institutional management environment and can be one of the Controlling, Resilience-building, or No-management system. The service-provider/manager agents become active when the institutional management system is either Controlling (CM) or Resilience-building (RB), Under No-management system, only two agents of land-owner and natural-connector act in the model.

The state of each productive land unit, which is the land-status, is identified by two attributes of land use type and land degradation class (land-degradation-class), as explained in Section 4.2.1. Each land unit has one of the five types of land uses, including crop-lands, grazing-lands, forest-lands, fishing-grounds, and built-up-lands. The severity of land degradation of productive land units is reflected in the land-degradation-class, which are slight, moderate, severe, and very severe, reflecting the level of severity of land degradation when it moves from 1 to 4 (Dregen and Chou, 1994; see Section 4.2.1). Non-productive land units are allocated to service providing centers (service-center), which are governmental. Land-owner agent performs on its land units, my-land, which is a productive land unit with specific land use type and land-degradation-class, as reflected as land unit attribute in

Table 5. Service-provider/ manager agent provides services to land-owners and works within one of the local service providing centers (service-center) that is located on non-productive land units. The natural connector (natural-connector) agent, which locates on productive land unit, ecologically connects land units through ecological networks, as explained in Section 1.1 and Section 4.2.1.

Activities of land-owner agents are ecologically space-related. Each land-owner is randomly assigned to one unit of land (my-land) with the specific land use type, but the agent can own more than one land unit in a competitive process of searching, stopping, making decision, as explained in Section 4.2.1. My-land-num reflects number of land units that an agent owns. It represents the wealth of the agent (Naidu, 2009; Section 2.1) and possible diverse activities that the agent can carry on when it faces disturbances (Schlüter and Pahl-Wostl 2007; Section 2.1). Variables and attributes are randomly initialized to the land-owner agent. The land management decisions by the land-owner agents are influenced by its own variables and attributes as well as its neighbors' attributes and decisions and the service providing management system, if applicable (see Section 2.1, Section 3.2, and Section 4.1.3).

Besides the state attribute of land units' identity of land-owner (my-land), each land-owner agent inherits a resilience score (my-resilience-score), which represents the agent's resilience (Section 2.1 and Section 4.2.1). The inherited resilience score of agent changes as a result of the decisions that is made by the agent over time and within the interactions of land units and agents. The changes of the agent's resilience could be either degraded (degraded-resilience?) or upgraded (upgraded-resilience?). The resilience-score of the land-owner agents makes them qualify for some actions, including leading groups and cooperation, as explained in Section 4.2.2.

For the learning procedure, each land-owner agent has a memory of past experiences that records the history of strategies and the result of the applied strategies in terms of the productivity of the land unit, which is stored as biocapacity. The sizes of individual's memory (memory-size), which represents the number of times that a land-owner agent remembers the past experiences, are different among the agents. In the memory of land-owner agent, a bag of strategies is located, in which the strategies and the productivity of them are stored. These strategies have different requirements. Each land-owner agent chooses the best strategy based on the past experiences and prediction, which follows searching, stopping, and making decision process same as the process that is applied in the case of El Faro Bar problem (Arthur, 1994), which is explained in Section 4.2.5. Also, the agent considers the requirements for implementing the best strategy. If the agent can fulfill the requirements, it chooses the best strategy, otherwise; the agent searches for the other strategy as the best strategy.

The strategies requirements could be the need for grouping with neighbors and the neighbor's capacity to cooperate, as well as technical, infrastructural, financial, and legal support, as explained in Section 2.1. If the strategy's requirements match the land-owner's status, the strategy is selected and the biocapacity of land unit is restored in the strategy history as the result of implementing the specific strategy. Knowledgeability (my-knowledgeability), whether or not the agent resists to the changes (i-resist-to-change?) as well as grouping (i-resist-to-group?), having access to required resources (i-have-access-to-required-resources?), and financially being supported (financially-supported?) are attributes that are initially assigned to land-owner agents but would change over time. As explained in Section 2.1, these attributes are part of the adaptive governance as the actors' and groups' capacities, which are specified for this model and presented in Table 2.

Table 2. Attributes of Land-owner Agent

NAME	DESCRIPTION	RANGE/UNIT	DEFAULT	REFERENCES
my-land	The agent owns a productive land unit with the xcor-ycor	One unit of land with xcor-ycor	One unit	Space identity of land-owner agent
my-land-num	Number of lands that an individual owns	1-10/ units	1	Naidu ,2009; Schlüter and Pahl-Wostl, 2007; Section 2.1
my-resilience-score	Each individual randomly has resilience score between 1 – 100, which changes over time	0-100 / score unit with two decimal random	Random between 1 and 100	Matin and Taylor, 2015
upgraded-resilience? /degraded-resilience?	Whether the individual's resilience is upgraded/degraded based on changing on the agent's activities	True/false	false	Matin and Taylor, 2015
memory-size	Size of memory (number) based on which the agent remembers the number of times of past history of its land management strategies and the result	0-10 / number of times	3	Arthur (1994)
number-of-strategies	Number of strategies that an agent may hold in its bag of strategies	0-20 /number of strategies	5	Arthur (1994)
my-strategies-need-neighbors-cooperation	Whether or not the strategies of the agent require neighbors' cooperation	One of [1 2]	Randomly 1 or 2	Chapin, Folke, and Kofinas, 2009
grouped?	Whether or not the agent is grouped with neighbors	True/false	False	Chapin, Folke, and Kofinas, 2009; Anderies et al., 2004; Janssen and Anderies, 2013
i-resist-to-change?	Whether or not the agent resists to change the strategy or adapt to the changes occur in its land	True/false	Randomly assigned true/false	Chapin, Folke, and Kofinas, 2009
i-resist-to-group?	Whether or not the agent resists to group with the neighbors	True/false	Randomly assigned true/false	Chapin, Folke, and Kofinas, 2009

NAME	DESCRIPTION	RANGE/UNIT	DEFAULT	REFERENCES
i-have-access-to-required-resources?	Whether or not the agent has access to required resources	True/false	False	Chapin, Folke, and Kofinas, 2009
financially-supported?	Whether or not the agent is financially supported	True/false	False	Chapin, Folke and Kofinas, 2009
my-knowledgeability	The level of knowledge that an agent has to decide on choosing a strategy and implement it	0-100/ randomly with two decimal	Randomly assigned	Chapin, Folke, and Kofinas, 2009

The service-provider/manager is a space-related agent that functions within the service providing centers (service-center) and organizations. Out of several capacities that service-providers could have, in this model, as explained in Section 1.2, each service-provider agent randomly receives two capacity attributes: corruption capacity (my-service-providing-corruption-capacity) and resilience-building capacity (my-resilience-building-capacity). Also, some of the service-providers under specific situations would confiscate land units of the land-owners and owns land units. In this case, my-service-provider-land? attribute becomes true. A small portion of service-provider agents (frac) in local and regional organizations are managers. Beside locality attribute, which is the same as my-service-center, managers have one attribute of whether or not corrupted (corrupted-manager?). The attributes, variables, and parameters of service-provider/manager agents are presented in Table 3.

Table 3.Parameters of Service-provider/manager Agent

NAME	DESCRIPTION	RANGE/UNIT	DEFAULT	REFERENCES
my-service-center	The center that service- provider belongs to	xcor -ycor	Randomly assigned	space-related identity of service-provider/manager agent
my-service-provider-land?	Whether or not a productive land unit is confiscated and owned by service-provider agent	True/ false	False	Luo, 2005; Section 2.3
my-resilience-building-capacity	The capacity of service- provider agent to build capacity in its service providing	1-100 randomly	1- 100 randomly assigned	Chapin, Folke, and Kofinas, 2009; Section 2.1
my-service-providing-corruption-capacity	The corruption capacity of service-provider	1-100 randomly	1-100 randomly assigned	Luo, 2005; Section 2.3
corrupted-manager?	Whether or not the manager is corrupted	True/false randomly	Randomly assigned	Luo, 2005; Section 2.3

Table 4. Attributes of Natural-connector Agent

NAME	DESCRIPTION	RANGE/UNIT	DEFAULT	REFERENCES
ctype	Natural-connector type of each productive land unit that connects lands based on the same ctype	One of [1 2 3 4]	Random	Jax, 2006; Jax, Jones and Pickett, 1998
partner?	Whether the natural-connector is in a network and has a partner or not	True/false	False	Barabási and Albert, 1999; Equation 1
number-of-my-links	Number of links of natural-connector agent if it is partnered and networked	Number: 0-max-degree	0	Barabási and Albert, 1999; Equation 1
my-ecological-resilience	The ecological resilience capacity of the natural-connector to hold disturbances	One of [1 2 3 4]	Random	Falk, Watts, and Thode, 2019

Natural-connector is a space-related agent type that locates on productive land units and connects land units through networking, as explained in Section 1.1 and Section 4.2.1. Each natural-connector agent has four attributes; ctype, partnered?, my-ecological-resilience, and if it is partnered and is part of any network it has the attribute of number of links (number-of-my-links), The ctype presents the type of natural-connector. Considering the ecological connectivity, natural-connectors with the same ctype has the potential of connecting to each other. The type of natural-connectors (ctype) could be one of the four types. The ctype is randomly initialized and assigned to natural-connector agents. As explained earlier in this section and Section 4.2.1, one of the attributes of the productive land units is land-degradation-class, which indicates the severity of the land degradation of land units. When land-degradation-class of a land unit, on which the natural-connector agent is located, changes to 4, which presents a very severe degradation of the land unit, the ctype of that land unit changes to 4 and becomes ready for networking with the other natural-connector agents that their ctype attribute is 4 (see Section 4.2.1). The partnered? attribute, is the false/true binary partnered in an ecological network. Initially, only one natural-connector agent has randomly partnered and over time and under certain ecological condition (see Figure 9) the network grows and more natural-connector agents partner with each other as the preferential attachment networking (Barabási and Albert, 1999; Section 4.2.1). The third attribute of natural-connector agent is number of links (number-of-my-links). The agent counts its links in the network, it receives 0 if it is not connected to another natural-connector agent. The maximum number of links that the agent can have is the maximum number of links of the network (max-degree). The fourth attribute of natural-connector agent is the ecological resilience (my-ecological-resilience), which is randomly initiated out of four options and represents the ability of the natural-connector to hold disturbances. Higher number of my-ecological-resilience means higher ecological resilience and ability to hold disturbances, which is explained in Section 1.1, Section 4.2.1, and Section 4.2.2. These attributes are presented in Table 4.

The links in this model forms through natural-connector agents, connect them, and act as corridors of transferring disturbances. Considering the preferential attachment structure of the network (see Section 4.2.1), the network has one binary true/false attribute of whether or not the link is connected from both ends (both-ends?).

The model has three collectives: group of land-owners, group of service-providers, group of land units. At the local level, the neighboring land units, which includes eight land units, connect and at a higher level the specific land units with certain land-degradation-class (see Figure 8) are connected through networking, as explained in Section 4.2.1. For this reason, the network carries disturbances (see Section 1.1), which gradually and exponentially grows.

Land-owner agents, also, group with their eight neighbors under specific conditions and going through a process of self-organization or making groups, as explained in Section 4.1.3. Service-provider agents informally form groups with their colleagues based on their local interest and their attribute of corruption capacity (my-service-providing-corruption-capacity). Therefore, a new attribute at the group level of service-provider forms and that is whether service-providers-corrupted-grouped?. In addition, they officially belong to another group and that is their local organizations and at the higher level are regional organizations. Except these local and regional organizations and somehow neighboring grouping, the other types of collectives are temporary and they change as the system changes.

There are global variables that are based for some of the properties of land units, land-owners, institutions, and network. Global variables for productive land units are numbers of land units for each land use type (num-crop-lands, num-grazing-lands, num-forest-lands, num-fishing-grounds, and num-built-up-lands) and for non-productive land units is number of land units for service-centers (num-service-centers). For land-owners, the global variables are number of population (num-population), memory-size, number-of-strategies, generally knowledge-required for management of land unit, and an overcoming-threshold, which is a threshold that the land-owner agent can accept to apply a strategy. Global variables for the institutions are types of institution-management, which are No-management (NM), Controlling (CM), and Resilience-building (RB), and corruption-capacity indicating the global corruption capacity in which service-provider agents perform and my-service-providing-corruption-capacity can be affected by this global variable.

Each productive land unit with specific land use type (see Section 4.2.1) has state variable of land-degradation-class, which are randomly assigned but changes over time based on the state variables of neighboring land units as well as their states in the land connection network and the decisions that are made by their land-owners (see Figure 8, Figure 9, and Figure 10). The severity land-degradation-class of land unit changes over time and in the process of actions and interactions between land units as well as between agents and land units. Also, each productive land unit has a biocapacity that is set based on the land use types and the land-degradation-class. The biocapacity of different land use type is extracted from the country-based foot print reports (Iran country report, 2012; see Section 4.2.1). The attributes of the land units are presented in Table 5.

The time in the model is virtual, and the time step is a type of expanded perception of real-time, which enables us to discover invisible actions and interactions between the individuals of the subsystems beyond real-time. Imagine in the case of this research there is the annual data that present some changes. To understand the data and changes, and to be able to observe actions and interactions that lead to the presented data, each year is expanded to 365 timesteps. These 365 timesteps do not represent days in the real world. So, there should not be expected real-world's logic for each time step. For example, land-owners in the real world do not decide to change their land utilization every second or over a day or even annually. But, in the virtual world of this model, land-owner agents monitor the changes every time step and decide whether or not they change their land utilization. These virtual timesteps enable this research to observe the ecological and social dynamics on the same scale, even though they cannot occur simultaneously. It can be concluded that every 365 virtual timesteps could represent a year but every time step does not represent a day. In other words, a year is divided into equal timesteps, but they are not days. Over those 365 timesteps, the actions and interactions are observed that cannot be seen over the annual data. For example, 1500 timesteps could be a bit more than 4 years, and 5000 timesteps could represent 13- 14 years. As the model is virtual, the data that is produced and analyzed is based on virtual time, and they should not be referred to as real-time. The running times period of the model is the number of times that the model is run to make sure that the outputs are consistent. For the final analysis, the model is run over 1500 timesteps for 50 running times.

Table 5. Attributes, Variables, and Parameters of Land Units

NAME	DESCRIPTION	RANGE/UNIT	DEFAULT	REFERENCES
num-crop-lands/ num-grazing-lands/ num-forest-lands/ num-fishing-grounds/ num-built-up-lands	The number of crop land units/ The number of grazing land units/ The number of forest land units/ The number of fishing grounds/ The number of building land units	Crop: 0-632 Grazing: 0 -162 Forest: 0- 48 Fishing: 0-128 Built- up: 0-88 gh unit	632 162 48 128 88	Iran country report, 2012 (https://www.footprintnetwork.org/)
num-service-center	The number of service providing center	0-30/number	30	
bio-per-capita	The biocapacity of each type of land use in global unit.	Crop: 0-0.72 Grazing: -0-0.16 Forest: 0-0.14 Fishing: 0-0.56 Build- up:0- 0.12 /gha unit	Crop: 0.36 Grazing: 0.08 Forest: 0.07 Fishing: 0.28 Build- up: 0.06 /gh unit	Iran country report, 2012 (https://www.footprintnetwork.org/)
land-degradation-class	Land degradation class of land units.	One of [1 2 3 4]	Random	Dregen and Chou (1994)
degraded? / upgraded?	The land-degradation-class of the land unit changes either degraded or upgraded	True/ false	false	Section 4.2.1
affected-by-negative-energy? / dead-land? /	Productive land unit is affected by disturbances and changes to dead-land.	True/ false	False	Barabási and Albert, 1999; Section 4.2.1
alive-land?	Productive land unit which is not affected by negative-energy	True/false	True	Section 4.2.1
land-owned? /available-land?	Whether or not the productive land unit is owned/ available to be owned	True/false	True/false	Section 4.2.1
land-owned-by-service-providers?	Whether or not the productive piece of land is owned by service provides	True/false	False	Luo, 2005; Section 2.3

4.1.3. Process Overview and Scheduling

The model process includes four main procedures through which land-owner agents have to decide for their land management strategy, Figure 8, Figure 9, and Figure 10. As shown in Figure 10, land-owner agents actively engage in two procedures of choosing the best strategy through learning process and self-organization, as discussed in Section 2.1, and will be explained in Section 4.2.5 and Section 4.3.4. Land-owner agents make decision by learning from past experiences and taking actions in self-organization procedure if the chosen strategy requires grouping and neighbors' cooperation (see Section 4.2.2 and Section 4.3.4). However, these two procedures do take part in conjunction with two other procedures that are carried out by natural-connector and service-provider/manager agents, as will be discussed in Section 4.2.2 and Section 4.3.4. The procedure of land connectivity, which includes networking and releasing disturbances, is taken by natural-connector agents, as shown in Figure 9. The procedure to provide services to land units and land-owner agents, which are different under Controlling and Resilience-building management, is a procedure that is taken by service-provider/manager agents. These procedures are interconnected and affect one another and update attributes, including land-degradation-class and land use type of land units, ctyp and partnered? of natural-connectors, and resilience-score of land-owner agents. It also, generates outputs at the system level, including system resilience status, as will be discussed in Section 4.3.4 (see Figure 12 and algorithm of system resilience status), total-bio, and total population.

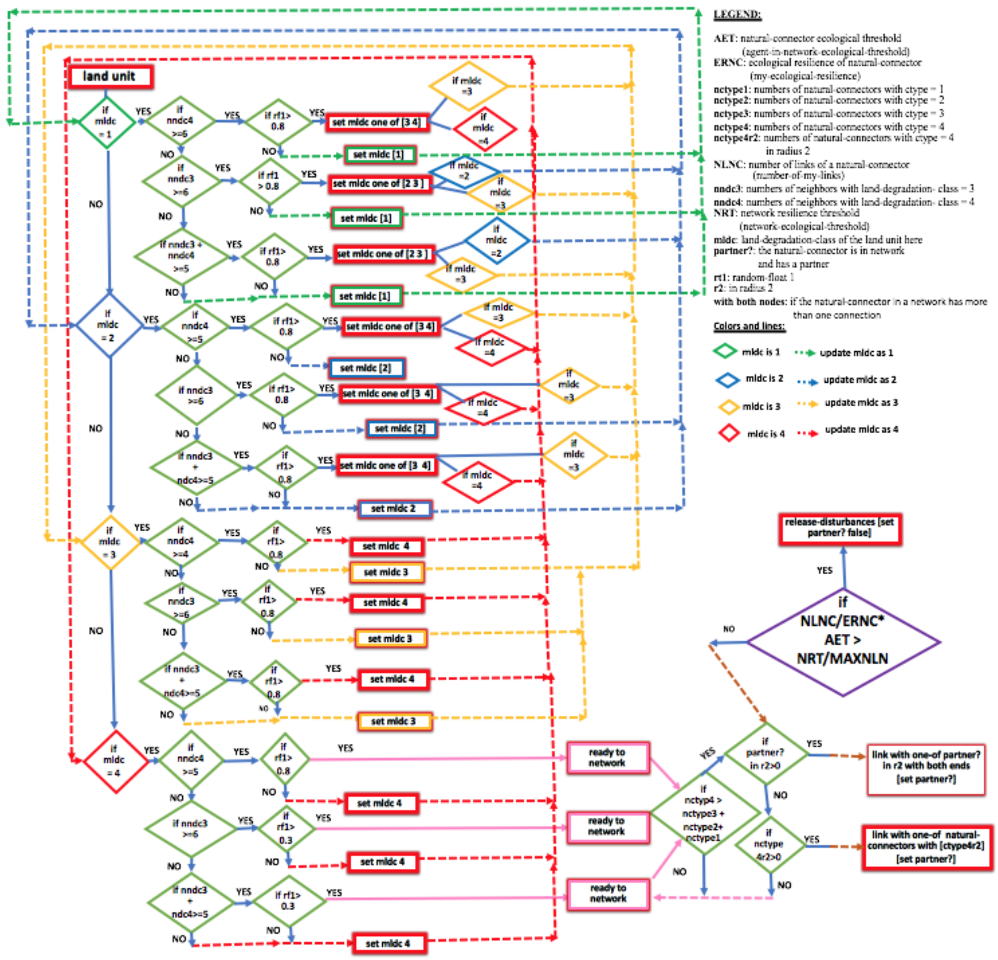

Figure 8. Connecting neighboring land units

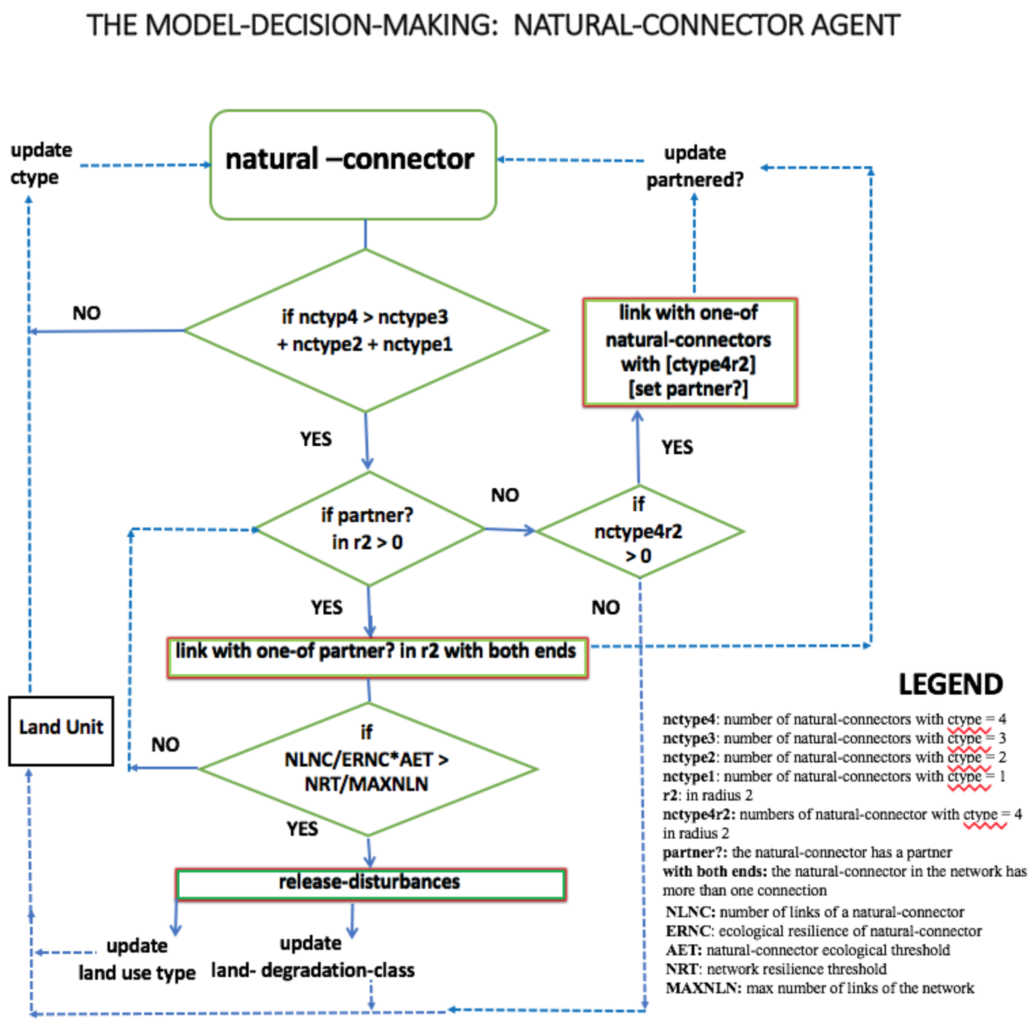

Figure 9. Networking and releasing disturbances by natural-connector agents

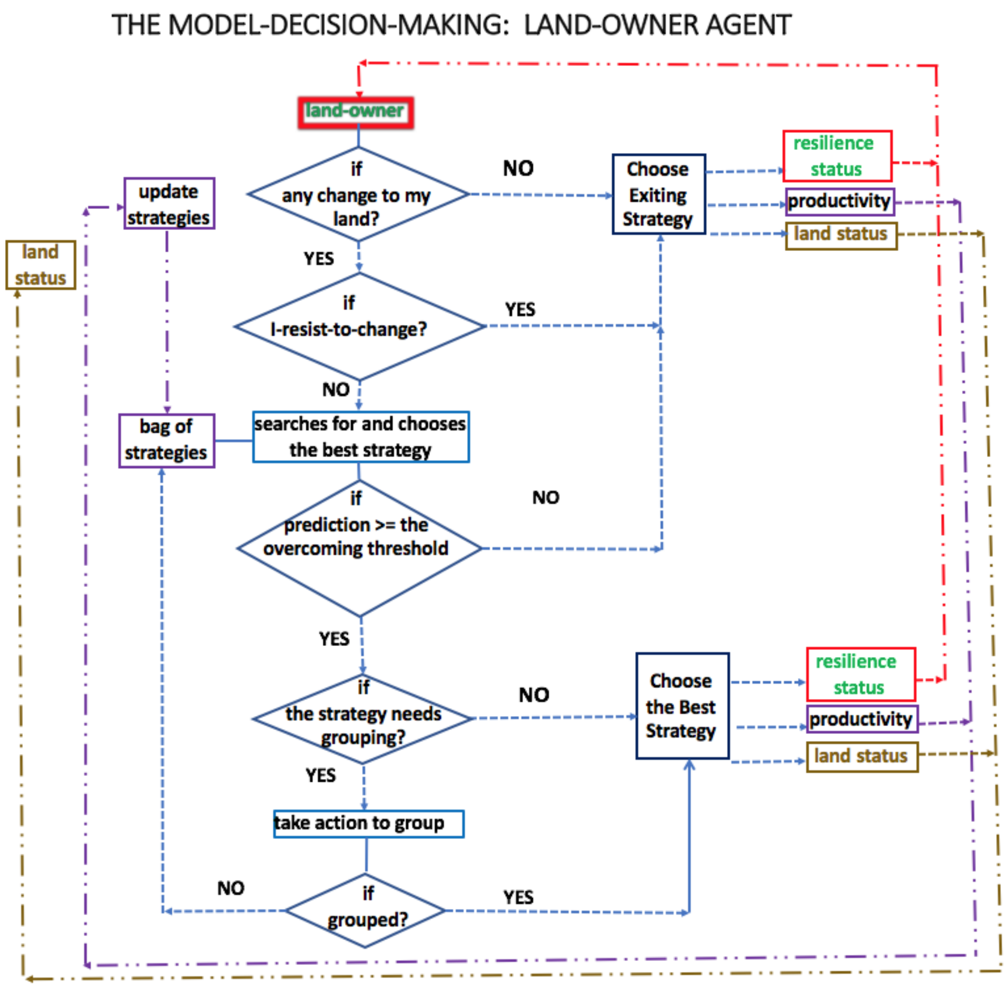

Figure 10. Decision process to choose the land strategy by land-owner agents

The detail of the procedures that land-owner agents go through in their decisions is presented in Figure 10. When a land-owner agent faces the change in its land unit, each it decides whether or not to change the land use strategy (not-change-strategy?). This decision is based on several land-owner's attributes and conditions. Not resisting to change (i-resist-to-change?) is the basic attribute for the decision of whether to change land use strategy. When the land-owner agent is not resisting change, it starts to search for and choose the best strategy as a part of learning procedure. In this search, the condition of if (prediction >= overcoming-threshold) becomes the criteria for further decision. The prediction is based on the chosen best strategy from the bag of strategies and reflects the productivity of land unit in biocapacity. Learning from the experience, each land-owner records the applied strategies and the results over times in its bag of strategy which is located in its memory. The productivity of the land, which is biocapacity of the land unit and recorded for each strategy, is the criteria for making decision to choose the best strategy. In addition to the implemented strategies, each land-owner agent may try to apply a strategy that has not been practically implemented yet, for which the land-owner predicts the productivity. The predicted productivity is recorded for the strategies that are not implemented and the actual productivity will be replaced when the strategy is implemented. Gradually, in the bag of strategies of land-owner the productivity of implemented strategies for the specific land is reflected with the predicted productivity for the possible strategies that are not implemented. Therefore, learning procedure is reflected in the bag of strategies of land-owner agent. In the process of making decision for the land, each land-owner chooses one of the strategies from its bag of strategies as the best strategy, considering the land status and in the comparison with the existing land practice.

For implementing the chosen strategy, land-owner goes through another process of making decision of self-organization mainly based on its own grouping capacity (i-resist-to-group?) and resilience status (my-resilience-score) as well as the neighbors. As explained in Section 4.1.2, each strategy may have some requirements, including knowledge, technical support, access to resources, capacity of grouping and neighbors' cooperation. Each land-owner reviews its own capacities to find out whether or not they match the chosen strategy requirements for further decision and taking action. In this process, if the land-owner has an attribute of resisting to make a group (i-resist-to-group?), it decides to remain with the current strategy (not-change-strategy?). In this situation, the end result is conditioned to the current productivity of the land (biocapacity) and predicted (biocapacity >= predicted /or biocapacity < predicted) (see Section 4.2.5). Therefore, the end result may or may not be desirable and consequently it may negatively or positively affect the resilience capacity of the land-owner (my-resilience-score) and land-degradation-class of the land unit. If the strategy requires grouping activities and the land- owner agent does have such a capacity it may choose to change the strategy. If the chosen strategy requires neighbors' cooperation the model follows the self-organization procedure, which is based on resilience status of the land-owner agent and its neighbors. As will be discussed in Section 4.3.2, the land-owner with the resilient-leading (rl) status (my-resilience-score >= 90), first checks the neighbors' resilience status. If there is any neighbor with resilient-leading (rl) status, the land-owner takes action and groups with those neighbors. Also, if there are neighbors with resilient-cooperating (rc)status (55 =< my-resilience-score <90), the land-owner agent takes action to get information whether those neighbors' strategies require cooperation. If it is so, the land-owner agent initiates to make group with them as well. For the case that those neighbors' strategies do not require neighbors' cooperation, they may or may not cooperate with the land-owner agent. The possibility of positive response to the land-owner's request for grouping would become less if the neighbors are resilient-owner (r) (21=< my-resilience-score < 55) and their strategies do not need neighbors' cooperation. The grouping action gets the least possible if the neighbors' resilience status is low-resilient (lr) (my-resilience-score < 21).

In the self-organization procedure, by decreasing the resiliency of land-owner whose strategy requires neighbors' cooperation, the possibility of taking action to make a group with neighbors becomes less except under the RB management system and the condition that the land-owner can be reached by the service-providers to be served. As a part of the management system's rules and regulations, service-providers under the RB management, encourage land-owner agents to cooperate and make groups if there are needed. Moreover, land-owner agents are supported to be grouped and cooperate. When a land-owner agent takes action to make a group with neighbors and going through the procedure of self-organization, if it reaches by service-provider, the service-provider negotiates with the neighbors who have less possibility to cooperate. Therefore, the possibility of grouping increases. In the same fashion, the possibility of improving land-degradation-class of the land units and the resiliency of the land-owner's as well as neighbors' (my-resilience-score) increases. In addition to these two procedures of choosing the best strategy through learning and self-organization, the land- owner agent's decision and the result of implementing the chosen strategy are affected by two main procedures of land connectivity and networking as well as service providing through institutional management system.

As presented in Figure 8, each land unit has a land-degradation-class attribute that reflects its degradation class status. Because of connectivity, the neighboring lands, which includes eight land units, affect one another in terms of the degradation status. Passing certain threshold, the natural-connectors of highly-degraded land units connect one another beyond their neighbors and form a network through which the disturbances flow. As will be discussed in Section 4.2.1, the network grows by following the preferential attachment network structure. It means the networks with higher numbers of land units in the network connect one another and finally the number of networks decreases while the number of land units for the larger networks increases. When the disturbances of any network reach the threshold (network-ecological-threshold), the natural-connectors of the network may release the disturbances if their networks individually could not hold the disturbances (see Equation 1). In other words, not all natural-connector agents release the disturbances when the network at the macro level passes the threshold (network-ecological-threshold). The release of disturbances by the individual natural-connectors follows their own ecological resilience (my-ecological-resilience) and individuals network threshold (agent-in-network-ecological-threshold) that can carry disturbances.

Releasing the disturbances affects the land units in the network and the severity of land-degradation-class of those land units extremely increases. When the land is affected by the disturbances it is hurt severely and it would be hard to restore it. Therefore, the land-owner agent of the affected land unit (dead-land) may either force to leave the land or make some decisions for its affected land. As shown in Figure 10 most of the land-owner agents who resist to change, may force to leave their land units if they do not have enough resources, (my-land-num >= 2). Still, there are land-owners who are resilient and may decide to restore their land units. If the resilient land-owner agents have access to required resources and enough knowledge they may restore their land units and, consequently improve their resilience score (my-resilience-score). However, it mostly happens if they do own more than certain numbers of land units that give them an option of relying on the other units of lands till the affected land units retains its productivity (see Section 4.2.1).

Under two different institutional management systems of Resilience-building (RB) and Controlling Management (CM), the situation of land-owner agents, whose land units are affected by disturbances, both management systems intend to restore them but with different approach of providing services. Also, for the affected land units by disturbances (dead-land), the land-owner agents may or may not receive enough support from the service-providers if their chosen strategy requires neighbors' cooperation under the Controlling Management system, as explained in Chapter Three.

Land-owner agents may need services for not only the affected land units but also making any decision to change their strategies if they feel some changes in their environment. These services could be access to required resources or required knowledge for applying different strategies. The type of institutional management system makes difference in the process of decision-making by land-owners and consequently in the increasing/decreasing the resiliency of individuals. Two types of institutional management, which are Resilience-building (RB) and Controlling Management (CM), completely are different in terms of their objectives, organizational structure for providing services, and the level of corruption that is tolerated in the organization, as will be discussed in Section 4.2.1. In the Resilience-building management (RB) system, the objective is to make individuals resilient while keeping the system resilient in terms of structure and function. In the Controlling Management system, the objective is to achieve a one-dimensional goal, which is to increase the productivity of lands at the system level even though it leads to extra cost and burden on individuals as well as decreasing the quality of lands. To support the institutional management system to achieve their goals, the model has a module to increase/decrease the number of service-providers. The module increases number of service-provider agents until reaching to the targeted goal of each management system. Then, the number of service-providers decreases as long as the achieved goal state is sustained. In terms of structure, in Resilience-building management (RB) system, service- providers go to the fields and meet land-owners to support if they need any. Under the Controlling Management (CM) system, the service-providers stay in the service-centers and land-owners go to the centers and meet them if they need any help. Moreover, in the Controlling Management (CM), there are efforts to stop land-owners from forming groups while in the Resilience-building management (RB) system, grouping is encouraged and supported by service-providers and the entire organization. However, not all service-providers/managers in the Controlling Management could or want to implement the organizational policy. Regarding toleration of corruption in two different systems, service-providers as well as managers with different corruption level communicate with each other either for supporting or fighting against. The service-providers/manages are the main agents for entire institutional management systems. Depending on management system, the decision of service-providers/managers follows the process of service providing. However, in the base-line model, none of these management systems apply, which is called No-management, and service-providers play no role in decision-making of land-owners as well as natural-connectors. Besides the role of service-providers to provide services to land-owners, service-providers/mangers go through organizational communication, which may or may not build capacity of organizations to improve the resilience-building procedure.

Under the Resilience-building management (RB) system, every service-provider is assigned to specific area to provide services to the land-owners and ensure about the quality of lands. As a result, service-providers constantly move and go to the lands to find out whether land-owners need help. If they find any land-owners with the very severe land degradation, they support them fully to improve the quality of their lands as well as their own resilience status. For the land units that are not degraded severely, if the strategies, which are chosen by the land-owners, require resources or specific knowledge, there is a high possibility that those services become available to the land-owners. Moreover, if the strategies that are selected by land-owners require neighbors' cooperation and grouping the service-providers try to facilitate the grouping process. In addition, the land-owners whose resilience capacities are low are supported by service-providers. The support could be any type, either financial, legal, technical, or access to resources that facilitate the land-owners to survive and thrive. These services could be provided by service-providers whose are not corrupted.

Learning from the case study, as explained in Chapter 3 and literature review of management system of SESs in Chapter 2, usually under the Controlling Management system, service-providers stay in the service-centers and land-owner agents who are seeking help go to the close by service-center. If the service-provider from whom a land-owner asks for help is corrupted there is a small possibility that it provides knowledge and requested access to resources. If the service-provider is not corrupted there is a bit higher possibility that service-provider agent provides such a requested service. In the same fashion, the service-provider agents with a low capacity of grouping most probably prevent land-owners from grouping even though the strategies that are chosen by land-owner agents require neighbors' cooperation. Despite the organizational policy, still, there is a possibility that a service-provider agent with the capacity of grouping to support land-owner agents whose strategies require neighbors' cooperation.

4.2. Design Concepts

4.2.1 Theoretical and Empirical Background

This explorative bottom-up model is based on complex adaptive system (Gunderson and Holling, 2002) and resilience thinking (Folke et al., 2010; see Section 2.1). The fundamental assumption of complex adaptive system, which is the constant interactions between active elements of the SES, and the hypothesis of unity of nature and human, whose parts constantly interacts at multiple levels, no matter if they are parts of nature or human, are taken and applied in this model. Therefore, in this model, parts, including three types of agents, as discussed in Section 4.1, individually and collectively, are in constant interactions and adaptively respond to the shocks and disturbances with uncertainty. When the parts face surprises, as the result of unknown constant interactions, they change their behaviors within the adaptive process. In this model parts apply self-organization and learning, which are two main characteristics of complex adaptive system, through which the systems adapt, evolve, and may transform (Gunderson and Holling 2002; Berkes et al., 2003, Folke, 2002). As a complex adaptive system, this model follows the main hypothesis of resilience as the capacity of SESs to retain their structures and functions after receiving shocks and disturbances (Walker et al., 2004; see Section 1.2).

Among a few applied ABM in complex adaptive system and resilience thinking (see Section 2.2), Schlüter and Pahl-Wostl (2007) have taken a bottom-up ABM approach and developed an integrative ABM, in which resilience of coupled social-ecological system to the short and long-term water scarcity has been investigated by understanding the linkage between three subsystems of social, irrigation, and aquatic ecosystem. In their model, they compared the resilience of different institutional settings of water management to water availability, in terms of variability and uncertainty. Even though the value of the model, which is developed by Schlüter and Pahl-Wostl (2007), is a two-way integrative bottom-up model with the interaction and linkage between social and ecological subsystems, still, the resilience is considered as the capacity of the system and the individual's resilience capacity as a factor that affects the resilience of the social-ecological system and is affected by the system resiliency has been ignored. For this reason, this model utilizes the psychological hypothesis of resilience in SESs, including one presented by Matin and Taylor (2015; see Section 2.1), which indicates that resilience could be as much as individually inherited that contextually learnt. Therefore, in this model, individuals of land-owner as well as ecological units each inherits resilience capacity, which are reflected in the attributes of my-resilience-score and my-ecological-resilience-capacity, respectively, as explained in Section 4.1. These inherited capacities can be changed over times, which is supported by the behavioral approach of individuals and social groups that are formed in a two-way process and social cultures and behaviors are created by individuals' perceptions and decisions (Kennedy, 2012). Therefore, the procedure of the model hypothesizes that in a social-ecological complex adaptive system, individuals in both ecological and social subsystems have different resilience capacities, and in an interactive adaptation process individuals as well as the system, through self-organization and learning, enhance different levels of resiliency that are required for either keeping the system's structure and function or transforming it to a new system, in which both human beings and ecological subsystems may live together as one single evolving system. However, it is questionable whether the system can gain its resiliency without any artificial or policy intervention. Therefore, this model explores whether the micro-scale learning and self-organization can lead to macro-scale resilience as argued by Berek (2000), or whether the artificial intervention is required, and if it is needed, which management system, centralized with controlling approach or decentralized resilience-building approach, can assist land-owners to perform with higher resiliency under uncertainty.

Schlüter and Pahl-Wostl (2007), through their ABM model of water use in a river basin, tested the performance of centralized verses decentralized management system under two different water uses. The first, irrigation is the only source of water use and the second, water use is diversified. Applying under different conditions, the process and the result indicates when irrigation is the only type of water use and under regular water fluctuation inflow the centralized system performs better than decentralized management. Under the diversification of water uses and applying resilience mechanism, decentralized management system performs better. In the same fashion, this model is seeking answer to the question of how different types of management affect resilience mechanism. For this reason, three types of management systems are applied with three types of hypothesis. The first one is based on the self-organization and learning from within the system and without any institutional intervention. The second type is Controlling Management which is featured based on the historical practices in the world especially in the Third World Countries Post Colonialism (Berek, 2000), the steady state resource management (Chapin, Folke, and Kofinas, 2009), and specific dominant management system in Urmia Lake Basin, as explained in Chapter Three. Therefore, in this model, it is assumed that Controlling Management system is featured by traditional providing services at the service centers, targeting one dimensional goal or variable, which is land productivity in this model, standing against formation of autonomous local institutions, which is against self-organization in this model, and dominant corrupted personnel that may lead to systematic institutional corruption. For this type of management, the model specifically explores whether a system can gain its resilience without giving enough space to individuals to go through learning and self-organization. This process may force institutions to adapt themselves to the changes through the individual service-providers' involvement if the institutions have not previously presented their capabilities of evolving. The third type of management system is Resilience-building (RB) management, which follows the resilience-building Stewardship-based guidelines (Chapin, Folke and Kofinas, 2009). In addition, in modeling Resilience-building management system, the linkage between vulnerability and resilience of SESs (Gallopin, 2006) is taken into consideration. Not only the vulnerability of systems to disturbances are different due to their capacities to cope and adapt, but also, the systems' social and ecological components respond differently to specific disturbances. Therefore, in this model it is assumed that under the Resilience-building management (RB) system, the service-providers take the responsibility of Stewardships and visit land units to support land-owners if they need any help. In addition, the organizations strategize their policies to protect vulnerable land units, and support vulnerable individuals to make them resilient. The local institutions, which is self-organization procedure and grouped land-owners, are supported by service-providers. Even though the institution has some corrupted personnel and managers, the systematic corruption cannot be tolerated. For this type of management, the system aims at fostering sustainability through reducing vulnerability and increasing resilience. This procedure complies with resilience-building procedure. Moreover, in a broacher about how to apply resilience thinking, Stockholm University, Stockholm Resilience Center, introduced seven principles for applying resilience-thinking in SES (Stockholmresilience.org, 2021), which are maintain diversity and redundancy, manage connectivity, manage slow variables and feedbacks, foster complex adaptive systems thinking, encourage learning, broaden participation, and promote polycentric governance systems. The organizational approach and policies for the Resilience-building management (RB) in this model, also, with different degrees meet seven principles.

Population and distribution of different land use types of productive land units as well as the productivity of them are based on the standard global Footprint (global hectare) and global biocapacity (global hectare per capita). The biophysically degradation of the land affects the productivity of land. Out of different classification of land degradation, considering the nature of the ABM in this research, which is intuitive, the expert-based of four classes of land degradation by Dregen and Chou (1994), which are slight, moderate, severe, and very severe, reflects the level of severity of the degradation of land that is closer to the objective of classification of land degradation in this model. With this definition, land status of every land unit's type is comprised of the land use type of the land unit and the degradation class of the land (land-degradation-class). Changing the ecological land status, which is presented in land degradation class, complies with the first and second laws of geography (Tobler, 1970;1999), in which not only the things that are closer to each other are connected more than the things in distance, but also the external can affect an area based on the area's internal state[22]. Therefore, each ecological footprint has a land degradation state, which heuristically has different class and changes as the result of the individual's activities or land uses and the neighboring land

[22] Regardless of whether or not they can be considered law (Tobler, 2004), the second geography law, which was proposed by Tobler (1999), is not as known as the first one. This is what and how he proposed the second law: "Philosophically, the phenomenon external to an area of interest affect what goes on in the inside; a sufficiently common occurrence as to warrant being called the second law of geography".

degradation class. Land degradation state of ecological footprint affects the footprint biocapacity value, which measures the footprint's productivity. Besides neighboring, lands connect each other through natural-connector, which represents some common ecological criteria, such as neighboring ecological footprints and connectivity of underground water function (Jax, 2006; Jax, Jones and Pickett, 1998). The ecological units will gain their unit's biocapacity states based on the states of the connected footprints. When the degradation class of the ecological units passes certain threshold, they gradually connect to each other as a preferential attachment of scale free network for their complexity topology (Barabási and Albert, 1999) and act with a sudden, unprecedented, and unpredicted ecological event, such as drought, salt wind, and heavy snow, and affect the whole system, which includes ecological, social-economic, and governmental subsystem. In comparison with the other networks, especially random and small world, the scale free network matches the entity of the model for its properties and mechanism that address the complexity of the case. According to Barabási and Albert (1999), the probability of connectivity in scale free is not uniform; the number of vertices grows over time by adding new verdicts, which means the network evolve over time; it represents preferential connectivity feature; distribution of local connectivity of large networks is free of scale and follows a power-law distribution. The scale free network is based on two generic mechanisms. First, the network expands continuously by adding new vertices, and second, new vertices attach preferentially to sites that are already well-connected. Therefore, the preferential attachment network addresses the complexity topology of the model, presents the "self-organization phenomena of large networks that goes beyond the individual particularity and the heterogeneity characteristic of network as a consequence of self-organization to the local decisions made by the individual vertices based on information that is biased toward the more visible (richer) vertices, irrespective of the nature and origin of this visibility.

As a computational model, it follows the heuristic based rule-action of mental model inductive procedure (Holland, 1986) for natural resources when human agents reason about their actions (Jones et al., 2011). In other words, the decisions of individuals is made intuitively by going through a simple heuristic procedure. The land-owners' choices are based on the assumption of bounded rationality (Simon 1955, 1956, 1990) for limited cognitive processing resources and capacities. In a dynamic cognitive process (Johnson and Busemeyer, 2010), the individuals make decision based on the knowledge and information that they acquire about their land units, their neighbors, the institutional rules, and what they have learnt from the past. The complexity of decision-making for land utilization is created by the unknown actions and interactions of the land units and unknown decisions by neighbors and their capacities to cooperation as well as the institutional management systems and service-providers' actions, especially under the uncertainty and risk due to drastic disaster. In the process of predicting and acting, individuals update their knowledge of applied strategies and store them in their bags of strategies, in which the high productive practices with higher biocapacity replace the low productive practices. Then, they adaptively choose the strategy that fits their situation. This complies with inductive-reasoning in the learning adaptive process that was applied by Arthur (1994) in the El Farol Bar problem solving case through ABM (Rand and

Wilensky, 2016). This is also supported by diverse heuristic methods especially Gigerenzer's Adaptive Toolbox (Gigerenzer and Gaissmaier, 2011), in which the threshold, prediction, and adaptive process are applied by using adaptive tool box to ecologically fit the heuristics and environment. In the adaptive process, the heuristic behavior follows three distinctive rules of searching, ending searching, and making decision, which all are cooperated in this model when land-owners strategically search for making decision for their land utilization.

Besides the theoretical reason for applying heuristic method in the model, practically the studies in the case of ULB do not formally represent the ecological and individual's behavioral decision-making. The model benefits from the studies in the area, which are mostly presented at the integrated level. However, the aggregated results of some of the behavioral and attitude studies are checked for verification with direct field visits and informal interviews. For example, a group of scholars (Pouladi, Afshar, Molajou and Afshar, 2020) intended to measure the attitude of farmers to save water and land conservation. Apparently, the scholars had all the theoretical and practical knowledge to design the questionnaire, collect the information, and analyze the data. Their analysis shows the relationship between size of farms, age, and education in water conservation. It means older and uneducated farmers have less intention for land conservation. This piece of information was not approved by the field visit and informal interview for the current research. What was missing in the survey by Pouladi et al. (2020) is the sense of belonging that cannot be described by education or age. The informal interviews and visits to the area as well as the expertise knowledge that was gained over the long time working with the system are the main input for the model of this research. This type of data availability prevents us from applying other data sources and statistics for parametrizing the model. However, the perception of the complexity of situation as well as behavior of individuals and organizations leads to develop an explorative model. In the history of ABM modeling, applying ABM as an exploratory abstract model gets back to the Schelling Segregation simple model (1971) that affected many human-environment studies. The other early abstract ABM model based study is Sugarscape (Epstein and Axtell, 1996). The objective of making abstract models is to create a virtual laboratory for studying. By availability of data, the tendency of researchers to model real world using the real data has been increased. Still it is a powerful tool when the required data is not available, same as this study. The explorative nature of the modeling encourages the modeler to place under scrutiny not only the procedure and process, which complies with the Pattern Oriented Modeling (Grim, et al., 2005), but also the parameters as the stylized facts (Miller et al., 2010), through which the major influential factors can be recognized and featured in the final version of the model. In other words, the model explores the resilience mechanism through understanding the importance of factors and variables in the process. Therefore, both factors and procedure are investigated through the modeling process. This process explores how inherent resilience, prosperity and diversity of activities, quality of their lands, affect the individual's qualification, including being cooperated and becoming resilient due to unknown disaster and stresses, and how it affects the resilience-building mechanism. In the same fashion, the model intends to understand how the quality of institutional management system affects the resilience-building mechanism, including providing service in the service-centers or in the field; being flexible in response to the ecological and individual need, including the affected or at the risk of affecting lands as well individual's financial and technical needs as the result of unknown disaster; monitoring against the organizational corruption; and controlling or supporting individual's behavior, such as grouping with neighbors. At the same time, the model explores how service-providers' and managers' individual's characteristics, including the capacity of corruption and grouping are important in the resilience-building process.

4.2.2 Individual Decision-making

Decision-making is modeled on three levels with their specific process: the system, group/local/subsystem, and individuals. At the system level, two types of agents make decisions: service-provider/manager agent and natural-connector agent of ecological networks; at the local/group/subsystem, the decision-makers are groups of land-owners, ecological units, and groups of service-providers; and at the individual level, all three agents representing land-owners, service-providers, and natural-connectors actively make decisions. The procedure of making decision concerning land occurs at three levels by the agents.

At the system level, based on the institutional management system, the authorities make decisions for the rules and regulations that are required to guide service-providers/managers. If the management system is Controlling (CM), the strategic goal is to make the system function by targeting one goal of achieving to certain level of productivity of land units. While the target is subject to change, in this model it is set to total biocapacity of 400 gha. because the ratio of population and biocapacity of the country is 1 (Iran country report https://www.footprintnetwork.org/, 2012). In this system, authorities decide for specific projects and rules to address the affected land units and land-owners due to severe disasters. To have control over the system, one of the main rules in this system is to stop and break any grouping among land-owners. The organizational rules for providing services at the service-center are made at the system level, but there is not any decision that is made at the system level to address the systematic corruption in the organization as well as the service centers. If the management system is Resilience-building (RB), the authorities' strategic goal is to make the system resilient by facilitating resilience building process for both ecology and social components at the individual levels while keeping the system function by considering the productivity at the system level. In other words, the system resilience status (system-resilience-status) has to stay at the Resilient (R) status (see Figure 12).

The service providing authorities also make decision to address the system's vulnerability before any disaster happens as well as to restore affected land units and support the affected land-owners due to disasters. They also make strategic rules to promote grouping of individuals whose strategies require neighbors' cooperation. Moreover, the authorities make organizational rules for service-provider agents to reach out the land units and land-owner agents to identify their needs and provide them services as much as they can. At the same time, they address systematic corruption in the organizations through managers and appointing service-providers who are not corrupted. For any type of the management system, authorities, also, decide to deploy or withdraw service-provider agents based on the aggregated data at the system level and considering whether or not the system reaches its strategic goal, which varies for each of the management system.

At the system level, natural-connector agents in the ecological network decide on when and where to release disturbances. In the wildland fire studies, (Falk, Watts, and Thode, 2019), Falk et al. explain the relationship between the spatial scale disturbance and patch quality, including diversity in size, density, and vegetation. In this research, also, the spatial scale of disturbances that is presented in releasing disturbances at macro system level, relates to the quality of each natural-connector of the network, which is reflected in the attribute of my-ecological-resilience for each natural-connector agent. When the number of links of any network that connects land units with severe degradation reaches to certain threshold the natural-connector agent decides to release disturbances. Consequently, the land units as well as the land-owners, within that network are at the risk of being affected. The threshold to release disturbances is a subject to change to find out how it affects the resilience mechanism. In this model, the disturbances can be released by considering the capacity of holding disturbances at both levels of micro for each natural-connector in the network and the macro for the entire network. In other words, each natural-connector in the network responds to the capacity of holding disturbances at the system level of the network based on its own capacity to hold the disturbances. The relationship between the network capacity of holding and releasing disturbances at the system level and the capacity of each natural-connector in the network is formulated as follows:

Equation 1. Releasing Disturbances

$$\frac{NLNC}{ERNC * AET} \geq \frac{NRT}{MAXNLN}$$

NLNC: Number of Links of a Natural-Connector (number-of-my-links)
ERNC: Ecological Resilience of Natural-Connector (my-ecological-resilience)
AET: Natural-Connector Ecological Threshold (agent-in-network-ecological-threshold)
NRT: Network Resilience Threshold (network-ecological-threshold)
MAXNLN: Max Number of Links of the Network (max-degree)

The face of the fraction on the right side of the equation is fixed for each model run, therefore; as the network grows the MAXNLN increases and the amount of the fraction at the right side becomes smaller. This means natural-connectors in the networks need fewer links (NLNC) to release the disturbances. However, not all natural-connectors with the same number of links can release the disturbances. The ecological resilience capacity (my-ecological-resilience), which reflects the quality of ecological diversity of each natural-connector at micro level same as the quality of patches in the wildland fire case, plays an important role. When the natural-connector's ERNC is higher, the resilience of the natural-connector becomes greater and the natural-connector needs more number of links to make the equation works and releases the disturbances.

At the individual level, natural-connectors, land-owners, and service-providers make decisions. Figure 8, Figure 9, and Figure 10 present how decisions are made at individual levels. Ecologically, decision at the individual level is made by natural-connector agents, who connects land units. In this model, to understand how the connected severely destroyed land units affect the system to emerge the unprecedented phenomenon of stress and disasters the connection of severely destroyed land units is targeted. The status of land-degradation-class of land units changes due to the decisions that are made by land-owners as well as the degradation class of the neighbors' land units. By computing the status of land units and their connectivity, when the number of severely degraded land units in a combination with the degradation class of the land units of neighbors reaches to certain threshold, the natural-connectors of severely destroyed land units, which is reflected in the variable of natural- connector type 4 (ctype4), decide to connect to one another by networking and form the networked ecological units. This computation and the threshold are subject to change and they are verified and presented in Section 5.2. As shown in Figure 8, the computing process and the thresholds are set as follows:

1. The land units with the land-degradation-class = 4 are candidates for global connection and entering the global network if they have one the following conditions:
    - the number of the neighbors' land units with land-degradation-class = 4 is greater than 5 with a high possibility/ or
    - the number of the neighbors' land units with land-degradation-class = 3 is greater than 6 with the lower possibility than the previous situation/ or
    - the number of the neighbors' land units with land-degradation-class = 3 & = 4 is greater than 5 with a lowest possibility.

Also, with high probability, the ctype of natural-connectors changes to ctype4 when the land-degradation-class of the land units, on which they are located, becomes 4. Even though the thresholds to join a network and release disturbances are subjects to change in order to explore their impacts on resilience mechanism, in this model, it is set with a simple rationality through which when a natural-connector with a ctype4 senses that global number of natural-connectors with ctype4 is larger than all other natural-connectors together (ctype1 + ctype2 + ctype3), which indicates the strength of degraded connected land units, it decides to randomly join a both ended network. Calculating the number of the links of networks, the natural-connector that is ready to network seeks a new partner in radius 2 that is not partnered and stronger than the other networks (see Figure 9).

The individual land-owner agents make three major decisions. One of them is whether or not to compete to own more than a land unit, on which they are located, without entering any conflict with each other. Another one is to choose the best strategy for land utilization and practices, which is adaptive learning-based process to choose the best strategy (see Section 4.2.5 and Section 4.3.4). The third decision that land-owner agents make is whether or not to take action or respond to actions for grouping and cooperating with neighbors, which is a self-organization-based process. Each land-owner agent initially has a land unit with specific land ue type, and some of the land-owner agents are willing to own more than one land unit. Therefore, land-owner agents decide on whether or not to search for available lands to own and when to stop searching. In this model, land-owners randomly intend to own more than one unit and start to move and search for available land units and stop searching when there is not any more land unit available. It is a constant dynamic through running the model because some of the land units could become available as the model runs.

The land-owner agents pursue the objective of land utilization practices decision, as shown in Figure 10). Therefore, one of the major decision that is taken by each land-owner agent is to choose the best land utilization strategy based for their situations. The agents intuitively try to find the best strategy by adapting their behaviors to the changing environment while evaluating the neighbors' situations and required resources. Searching for the best strategy is influenced by the memory of the past experiences of the productivity of strategies. Even though uncertainty is not explicitly included in the individuals' decisions, each land-owner agent evaluates the productivity of the land unit by comparing the actual productivity of the chosen strategy with the predicted for further decisions (see Section 4.2.5). The strategy that any land-owner agent chooses may need the neighbors' cooperation. For this, each land-owner agent, by considering its own grouping capacity decides on whether or not to make a group with its neighbors. Also, each land-owner assesses the possibility of grouping based on its own resilience status (my-resilience-score) as well as the neighbors to decide whether or not to lead grouping or to respond to the grouping request by neighbors. For any reason that makes grouping impossible, the land-owner agent decides to adapt to the situation by choosing different strategy.

To make the resilience score understandable and applicable especially for self-organization procedure, the resilient scores are categorized to four, considering the resilience study by Matin and Taylor (2015) (see Section 2.1).

- resilient-leading (rl): land-owner agent with my-resilience-score >= 90
- resilient-cooperating (rc): land-owner agent with 55 =< my-resilience-score < 90
- resilient-owner (r): land-owner agent with 21 =< my-resilience-score < 55
- low-resilient (lr): land-owner agent with 0 =< my-resilience-score < 21

Within these categories, individuals with resilience score higher than 90 out of 100 are considered resilient- owner (r) agents who could step up for any grouping if their strategy need neighbors' cooperation. land-owners with resilience score between 55 and 90 are resilient agents who are willing to cooperate and making group with neighbors but they don't initiate grouping. individuals with resilience score between 55 and 21 are resilient-owner agents, but their cooperation and grouping are less than the cooperative individuals, and individuals with less than 21 are low-resilient (lr) agents that the probability of cooperation is low and conditional. Self-organization starts with resilient-leading land-owner agents and the other's cooperation depends on their resilience status and their strategies' need for cooperation. The logic and thresholds are subject to investigate by varying them over running the model.

At the individual level, service-providers make two types of decisions. First, they decide how to apply rules and regulations in the field by considering their own personal characteristics and capacities as well as the situation of the lands and land-owners to whom they provide services. Second, they decide for their own organization and institution by communicating with their colleagues as well as their managers. The decision to communicate is based on whether the service-provider is corrupted or not and whether the service-providers with whom they contact are corrupted or not. If the portion of service-providers, who are corrupted is more than those who are not corrupted they may decide to make groups, which may provide them the opportunity to occupy some of the lands whose owners are forced to move out. However, if the service-providers who are not corrupted recognize any corrupted service-provider, they may decide to communicate with the managers at the higher level. The decision about the corrupted service-providers is taken at the higher local level.

At the group/local/subsystems level, natural-connectors and group of service-providers as well as managers make decisions. Natural-connectors with ctype4 that are already in the network decide to attach to the more powerful networks, based on the preferential attachment structure. Service-providers who are grouped based on their corruption capacity decide whether or not to seize the lands of land-owners who are forced to move out. The managers, also, decide on whether or not to remove corrupted service-providers about whom they received the corruption report.

4.2.3 Learning

Learning is part of making decision by agents individually and collectively. In this model, learning takes place when the decision-making rules change because agents exchange the information with each other and through this process the agents are forced to change their decisions.

The model has the learning-based decision-making module, in which each land-owner agent has a memory of past experiences and constantly update it for the time when individual seeks the best strategy and chooses it by reviewing the past experiences. In other words, the land-owner agent learns from its own past experiences for making decision. In addition, when land-owner agent learns that the requirements of the chosen strategy, including grouping capacity or neighbors who can cooperate, could not be met, the agent adapts and chooses a new strategy that is not as the best one as the previous one but it is the best strategy according to the agent’s condition. So, the agent learns and adapts. Moreover, learning at the collective takes place in the self-organization module, in which land-owner agents learn about the value of cooperation and grouping that provide the neighbors with the option of deciding to cooperate and group with the other neighbors.

Learning, also takes place in the ecological sub-system. Natural-connector agent of each land unit learns when, to whom, and how connect to the other natural-connector agents and make network beyond the neighbors. Moreover, when the network is in the developing process, natural-connector agents have the capacity of learning how to find the larger network to link to. While natural-connector agents of severely destroyed lands, which is reflected in the variable of ctype4, find each other and make network, they change the rule of networking when they learn that the disturbances is stronger than what network can tolerate and it should be released.

4.2.4 Individual Sensing

Besides ecological footprints of land units that locally sense, three agents of natural-connectors, land-owners, and service-providers/managers can sense the states and information, locally and globally, about themselves as well as the other agents and the environment and make decisions and acting upon the acquired information. Moreover, the agents exchange the information and knowledge at the collective and network levels to act together. Most of the variables are endogenous and are changed over time as the model runs. Besides institutional management system, there are variables that do not change when the model runs and can be considered exogenous variables, even though they can be set by user when the model is set up. The agents' settings for the number of service-centers for service-providers and memory-size, number-of-strategies, overcome-threshold, and knowledge-required for the land-owner agents are exogenous.

Each land unit or ecological footprint can sense the local information about itself and neighbors, calculates and comes up with new information, and changes its land status based on the acquired information. In addition, each land unit senses the information about being owned or becoming available to be owned by either land-owner agents or service-providers. Each land unit senses its land use type and land-degradation-class and calculates productivity of its own land unit. Meanwhile, it can sense the same information about its eight immediate neighbors, and changes its land-degradation-class based on the neighbors' information. Moreover, land units can remember the history of their land use types and land-degradation-class, however, the memory-size of land-degradation-class is very short and just can go back one step and remember previous land-degradation-class. Therefore, each land unit can calculate whether it can be upgraded or degraded by comparing the current land-degradation-class with the previous one.

Natural-connector agents sense their own connecting types (ctype) and the ecological resilience capacity of the land (my-ecological-resilience) to which it belongs. Natural-connector agents are randomly inherited both of these variables. They also, sense the land-degradation-class of the land units, on which they are located that may change the connecting type (ctype) of the natural-connector. Beside this local piece of information, natural-connector agents globally can sense the type of other natural-connector agents and decide on whether or not to connect. In this model, natural-connector agents with the connector type of 4 (ctype4) can find each other and get the information whether or not they are connected to any network (partner?). Each natural-connector agent, also can receive the global information about the network and decide to which network it would connect ("both-ended?" and "num-my-links"). Moreover, natural-connector agents within the network can sense the pressure of disturbances and decide on when and how to release it. In this process, each natural-connector in the network senses the number of its links (num-my-links) and calculates whether the ratio of its number of links to its ecological resilience capacity (my-ecological-resilience) and the threshold (agent-in-network-ecological-threshold) is greater than the ratio of the network threshold (network-ecological-threshold) to maximum number of links of the network (max-degree) (see Equation 1).

Agents representing land-owners sense information about themselves, land units, and other agents locally and globally for most of the decisions that they make. Each agent knows about the state of its own land units and the neighbors, which includes the location of land units (my-land) and number of land units (num-my-land) that they own and the status of each land unit, which includes the land-degradation-class and land use type of each land unit. Also, they are aware of their own capacities and the neighbors, including resilience capacities (my-resilience-score). There are some attributes that individuals are not directly aware of them and they have not been determined for them in advance. These attributes become known to the agents when they need to know about them. In other words, they are randomly assigned when they are needed. To be resistant to the changes (i-resist-to-change?) or the grouping capacity (i-resist-to-group?), knowledgeability (my-knowledgeability), and resource required (i-have-access-to-required-resources) are some of the variables that individuals become aware of when they receive a random number. For some of the attributes, the land-owner agents have to go through a process to become aware of them. For example, for knowing about the number of land units that the land-owner agents own, they have to go through the procedure of owning land. It is the same for knowing whether or not they are grouped with the neighbors or whether their resilience scores are upgraded or degraded. In addition, when there are severe disturbances, some of the individuals decide without recognizing the severe changes on their land units because not all land-owner agents feel the changes. In the self-organization procedure, even though every agent knows about its own resilience capacity (my-resilience-score) and the neighbors', none of them are sure about the possibility of cooperation of neighbors toward grouping. Over the negotiation, the neighbors may cooperate and form a group. However, there is no delay in terms of time step. In the strategy selection procedure, agents know about their land units and their own capacities but they choose the strategy as the best based on the past experiences with uncertainty. However, an explicit mechanism is modeled to give enough information to land-owners to choose the best strategy (see Section 4.2.5 and Section 4.2.2) Also, none of the land-owners know about the rules and regulations that service-providers apply. In the Controlling Management (CM) system, the land-owner agents become informed about the rules and regulation when they go to the service-centers. In the same fashion, under the Resilience-building management (RB) system, land-owners become aware of the rules, regulation and supportive projects when the service-provider agents reach them. It should be added that the corruption of service- providers and managers are not known to land-owner agents. So, when land-owner agents face the corrupted actions, such as seizing their land units by service-provider agents they comply with.

Service-provider agents are aware of their own capacities, the organizational rules and regulations, and the supportive projects. However, they receive information about the corruption of the other service-providers when they accidently see each other. Regarding the action against the corruption in the organization, service-provider agents have no information. Only managers are aware of if there is any. Also, service-provider agents know about the land-owner agents and land units that they serve.

Explicitly or implicitly, there is not any cost included in the model for acquiring and gathering information.

4.2.5 Individual Prediction

The model does not include any general prediction about the future conditions. The only prediction is the one that would be made by land-owner agents to predict the productivity of their land units for different strategies. This prediction is adapted from the simple learning technique of applying inductive reasoning and bounded rationality in the ABM for the El Farol Bar problem (see Section 4.2.1). This model, which was inspired by Arthur (1994), was programed by Rand and Wilensky (1997).

The prediction of land-owner agents is conceptualized in two main procedures of choosing the best strategy through learning process and updating the strategies. Through these procedures, every land-owner agent predicts the productivity of its land as the land's biocapacity for upcoming time. To do so, these agents have access to a set of prediction strategies and the actual biocapacity of the land from the time before. The predicted strategies are restored in a list of weights, which is a list of random numbers between -1 and 1. This list of strategies represents what the agent considers as the biocapacity prediction for the current time, which is affected by the historical data. One of these weights (the first one) is a constant term which allows the baseline of the prediction to be modified. Therefore, the land-owner agent decides on choosing the strategy by determining which one would have done the best if they had been used in the preceding times. In this way, the agent optimizes its prediction of biocapacity instead of optimizing the implementation.

To clarify the prediction procedure, it should be notified that every land-owner agent has a random number of potential strategies that is bounded within the identified number-of-strategies variable. Within the given strategies, each time, the agent chooses a strategy based on the previously predicted biocapacity and changes the strategy based on the performance over time. Each land-owner agent has a memory-size and a bag of strategies and remembers its strategical practices and the productivity for the times that is equal to the memory-size of each agent. In other words, every land-owner agent has a size of memory (memory-size) whose length reflects the number of times as the history that the biocapacity of the land's productivity could be restored and used by the agent to predict or evaluate a strategy. The performance evaluation is reflected in the update strategy procedure, in which the strategies cannot be changed but the strategy is updated by recording the biocapacity result of testing each strategy as the performance of the given strategy. And then selecting the strategy that has the best performance given the current data. In order to test each strategy, each land-owner has a historical performance data on the length of the memory-size, so that a strategy can be tested against the past performance that goes back for the times equal to the length of the size of memory, still using the full size of memory data to make its prediction. There is an overcoming threshold (overcoming-threshold) that the agent compares the predicted biocapacity with the overcoming-threshold and decides whether or not to accept a prediction. Beside the overcoming-threshold to accept a prediction, each strategy has a requirement as an attribute that is considered by the agent to accept a prediction. The requirement is whether or not the strategy need neighbors' cooperation. If it needs and the agent's condition doesn't comply with, the agent searches for the different strategy as the best strategy.

4.2.6 Interactions

Besides the interaction between the eight neighboring land units that affects the land-degradation-class of the lands, there are direct and indirect interactions between three types of agents as well as networks and collectives. The interactions between land-owner agents are direct through the self-organization procedure and indirect through the connection between their land units. In the self-organization procedure, the agents, individually or in a group, communicate with each other and act together. This interaction takes place through communication. If the chosen strategy by any agent needs its neighbors' cooperation and the land-owner agent has the resilience leading capacity, it goes to the neighbors and negotiates with them for grouping. The interaction between service-provider agents as well as between service-provider and land-owner agents are direct. Either in Controlling Management (CM) system, in which land-owners go to the center for receiving support or in the Resilience-building management (RB) system, in which service- providers go to the field and meet land-owners to find their needs for support, direct communication takes place. Also, service-providers either staying in the center or moving around to help land-owners, communicate with each other through the organizational communication procedure. The interaction between service-providers and their managers is also direct. In this procedure, the interaction between service-providers as well as between service-providers and their managers is one of three types. The first type is to see a corrupted service-provider and catch it and introduce it to the manager. The second type is to form a group based on their corruption status and they act together as a group. The status of the corrupted group in comparison with the not corrupted group affects the action that a group takes, such as forcing low-resilient (lr) land-owners to move out and seizing their lands. The managers do not interact or communicate with each other.

The interaction between natural-connector agents are direct and when they form a network and intend to release disturbances, the interaction between natural-connectors and the other two agents become indirect and through the impact that they have on land status of the individuals' lands and consequently the land-owner agent communicates indirectly. Also, the service-providers' as well as land-owners' interactions with natural-connectors are indirect and through the impact of their projects or land utilization, the connecting type (ctype) of natural-connector agents' changes.

4.2.7 Collectives

Two types of collectives and groups are modeled between natural-connector agents and land-owner agents. The type of network that natural-connector agents form is not imposed by the modeler but it forms based on increasing the number of natural-connectors with the ctype4 compares with the other types. The natural-connectors in the network also decide and act together to release the disturbances. However, the grouping between land-owner agents does not form under aggregation but being grouped is an attribute that individuals receive under certain conditions. Not every land-owner agent is capable of being grouped or, if the agent has the grouping capacity, not all those agents with the certain score of resilience can make a group or join a group. Still, the type of grouping among land-owner agents can be considered the imposed one by the modeler. When the chosen strategy by the land-owner agent requires the neighboring cooperation, they may form a group, which may positively affect and upgrade their resilience status and their land status.

4.2.8 Heterogeneity

Heterogeneity is the foundation of this model and all three agents' types are heterogeneous. The heterogeneity of land-owner agents can be found in all their attributes. They are heterogeneous in their land use types and land degradation class; the number of lands that they own; their resilience score; their capacity to group; their status to resist change or to grouping; their access to resources and knowledge; and their memory size, and the number of strategies in their bag of strategy. The natural-connectors are heterogeneous in their attribute of connecting types and the ecological resilience capacity. The service-providers are also heterogeneous in their attributes of corruption status and grouping capacity.

The processes of the model and procedural modules are the same for all agents but depends on the agents' attributes and state variables they may go through different procedures. For example, land-owner agents whose lands are affected by disaster may go through two procedures that the other individual agents do not. In the same fashion, to meet the model objectives, the procedure of networking and releasing disturbances is specific for the lands that their conditions make them ready for natural-connector agents with ctype4 to take action and go through the procedure. Obviously, going through the procedure of service providing depends on which type of management system is selected. Under the No-management system, none of the institutional management system is applied. For the two other types of Controlling Management and Resilience-building, there is a general procedure of service providing that is common between two systems but for each management system there is a specific procedure that service-providers go through one of them based on which management system is selected.

4.2.9 Stochasticity

The distribution of the space to the location of the agents, the number of each agents, and the state variables and attributes of the agents are all randomly assigned. Land use type and land degradation class are two attributes of the land units that are randomly assigned and affect the decisions that are taken by land-owners and natural-connectors, located on these lands. The attribute of connecting type of the ctype and ecological resilience capacity are randomly assigned to the natural-connector agent. Resilience score of land-owner agents as well as the memory-size, the number of strategies, resistance to grouping, resistance to change, access to required resources and knowledge are some of the land-owner's attributes and state variables that are assigned randomly. Service-providers are randomly deployed to service-centers. The attributes of being corrupted and capacity to grouping are two attributes of the service-providers that are randomly assigned to service-providers. In addition, when the model runs, the attributes randomly change as well.

When the model runs, land-owner agents randomly move to own lands and choose the best strategy out of a bag of strategies that are randomly assigned to them. The chosen strategy affects the land status, including land use type and land degradation class. Moreover, individual agents remember the past experiences back to number of times that matches the size of memory that is assigned randomly and each individual has different size of memory. In addition, the land status of neighbors with certain condition randomly affect each other. However, natural-connectors as well as land-owner agents do not receive the same effect when the status of the land units, on which natural-connectors located or land-owners own, change. For example, the attribute of connecting type of not all the natural-connectors changes to ctype4. Therefore, the randomness makes the land connection procedure less predictable, linear, and straight forward. It is same in releasing disturbances by the ecological network. Not all land units and land-owner agents with the same conditions are affected the same when a disturbance occurs.

4.2.10 Observation

The main data that are observed and collected over time, the 1500 time steps, are the changes in the following values:

number of land-owner agents with different resilience class (resilient-leading, resilient cooperating, resilient-owner, low-resilient);

number of land units with different land use type;

number of land units with different land-degradation-class;

number of land-owner agents own land units;

number of land-owner agents who are grouped;

number of population;

number of service-providers; and

system-resilience-status

Moreover, at the end of 1500 time steps the following outputs as the cumulative data at the system level are collected:

total-bio;

minimum and maximum degree of ecological network;

number of land units in the ecological network; and

number of land units affected by disturbances as dead-land.

4.3 Details

4.3.1 Implementation Details

The model is programed in NetLogo 5.3.1. With the user-friendly interface, NetLogo allows users to change the input sliders and visually observe the changing outputs. The model can be made available upon request. The model's simple interface is shown in Figure 11 for the Controlling institutional management system.

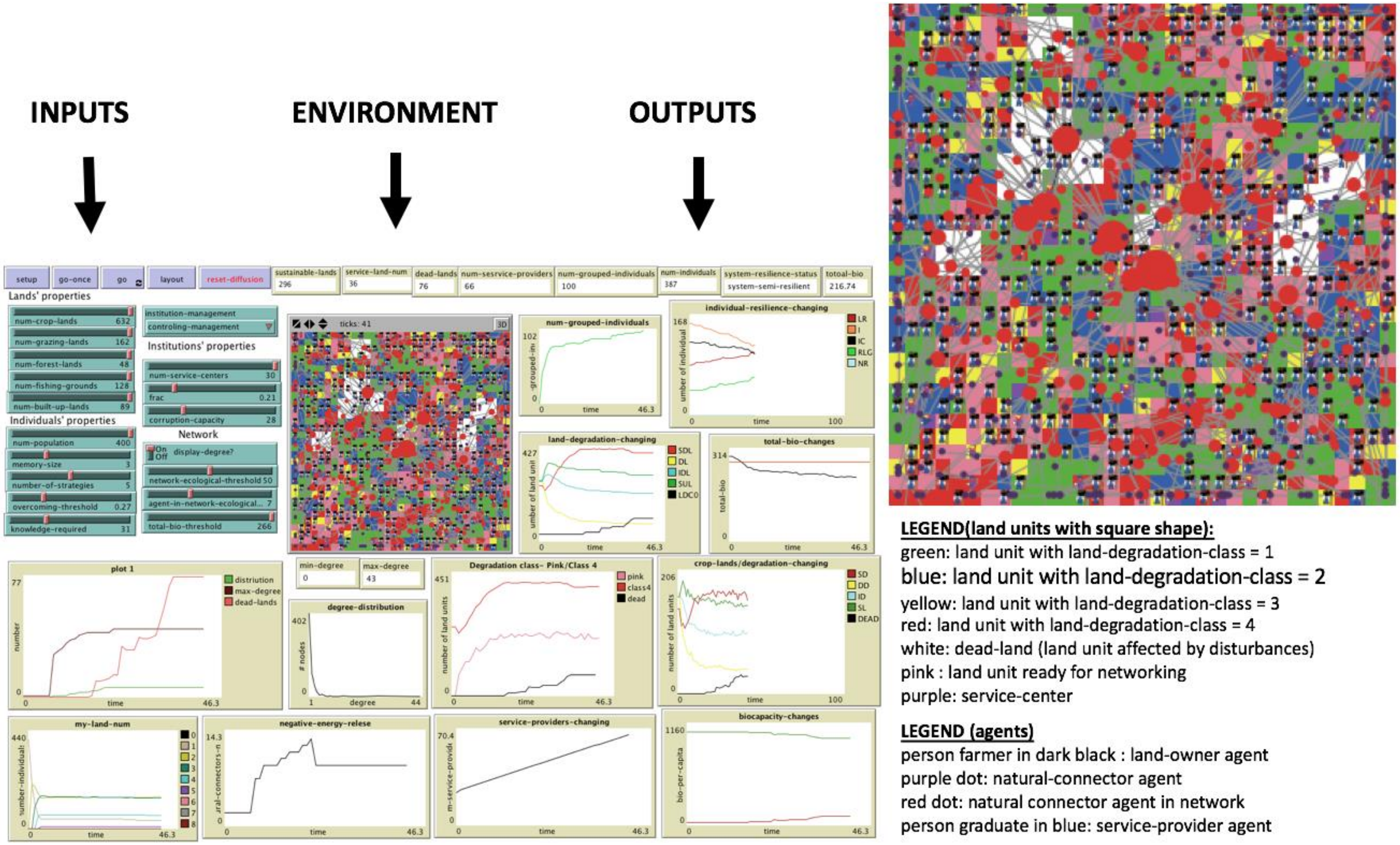

Figure 11. The model environment

4.3.2. Initialization

The model is initialized by a random distribution of the artificial world to the productive land units, which are locations for two types of agents of land-owners and natural-connectors, and non-productive land units, which are the location for service-providers/managers. The numbers of each agents follow the global variables, which are subjects to change by user (see Section 4.1). However, the numbers of land units with different land use types are set in portion of each type in the country of Iran and the total of population. The initialization of the model follows the order of different land use type of the productive land units and then service centers, which may make the results of the model sensitive to this order. The initialization includes the number of land units, which is 1058, the types of land use, which are five and include crop-lands, grazing-lands, forest-lands, fishing-grounds, and build-up lands, and the numbers of land units for each type of land use, which is 632 for num-crop-lands, 162 for num-grazing-lands, 48 for num-forest-lands, 128 for num-fishing-grounds, and 89 for num-built-up-lands. These numbers are proportionally calculated for the model based on the country report of Iran in 2012 by Footprint Network (2020). The model's result could be sensitive to the portion of each land use type, but they can be changed by the user. Also, each productive land unit is randomly assigned to one of four class of land degradation (land-degradation-class) that can be changed over time due to decisions of land-owners, the land-degradation-class of neighbors, as well as the possible connection beyond the neighbors. The productivity of land units, which is the biocapacity of land units, is based on biocapacity for each land use type (biocapacity) by considering the land-degradation class of the land-unit. The attribute bio-per-capita numbers initially are crop-lands: 0.36, grazing-lands:0.08, forest-lands:0.07, fishing-ground:0.28, Built-up-lands:0.06. In calculation of biocapacity of each land unit based on its land degradation and land use type, an Equivalent Productivity Coefficient (EPC) is applied. Even though it is arbitrary, the EPC has a long history in yield estimation in agricultural sector (Adetiloye, Ezedinma and Okigbo, 1983). EPC for land-degradation-class 4 is 0.25, for 3 is 0.5, for 2 is 0.75, and for 1 is 1. Multiplying EPC by the bio-per-capita of each land use type generates biocapacity of the land unit based on land-degradation-class and land use type. It is obvious that the biocapacity of land unit decreases when its land degradation class increases (see Section 4.2.1).

The result of the model could be sensitive to the model assumptions, state of variables, and the values of the variables to which they are randomly assigned. Even though the assignment of values is arbitrary, they follow the internal logic of the model by using the stylized factors (Miller et al., 2010) and the agents' logic mental decision model (Holland, 1986; Jones et al., 2011). Table 2, Table 3, Table 4, and Table 5 present the model variables and attributes and their initial values.

4.3.3 Input Data

The model is not linked to the external data sources file, even though the number of population and number of each land use type unit are proportionally calculated based on the Iran country footprint report (Iran country report, 2012). Also, the biocapacity for each land use type (bio-per-capita) is based on the same report.

4.3.4 Sub-models

This model is built on several major sub-models and some simple calculation outputs. The sub-models include decisions and actions by three agent types. For the agents representing individual humans, the sub-models search for and own more than one land unit; choose best strategy through learning process; take action to self-organization if the chosen strategy needs neighbors' cooperation; and build resilience by increasing the knowledge. In case of severe disturbances, the land-owner agents whose land units are affected by disturbances go through a decision-making procedure, in which they may be forced to leave or make decision that is quite specific for the affected land units. Natural-connector agents decide and take action through two sub-models of networking and connecting lands and releasing negative energies. The third type of agents, service-provider/ manager agents do their jobs through two sub-models of providing services and communicating within the organization. Besides these two sub-models, under the Resilience-building management (RB) system, for providing services, the service-providers first have to move around and visit the fields. So, in the Resilience-building management (RB) system, service-providers follow three extra sub-models. The sub-models are all conditional.

Land-owner agent searches and owns more land units: Each land-owner agent is randomly assigned a piece of land when the model is set up to run. As the number of land units are more than number of population, there are available land units to be owned. When the model runs, some of the land-owners search for available land units and own more land units. Therefore, if a land-owner agent is capable, it starts to search and own more land units.

Land-owner agent searches and chooses best strategy through learning process: When a land-owner agent finds any changes in the land status, it decides whether to change the existing strategy. The land-owner agent predicts the productivity of the land for its existing land use and practice considering the change. The productivity is measured by the biocapacity of the land unit. There is a global overcoming threshold (overcoming-threshold) for accepting or refusing specific land use and practice strategy. If prediction is less than overcoming-threshold, the land-owner agent decides to not change the strategy to utilize the land and the practice (not-to-change-strategy?). And if prediction is greater than or equal to the overcoming-threshold, the land-owner agent decides to change the strategy. Each strategy has some requirements, including neighbors' cooperation. If the chosen strategy requires neighbors' cooperation but the land-owner does not meet that requirement, the agent decides to start search and choose best strategy. Obviously, if the land-owner is the agent who resists any changes, it decides to not change the strategy regardless of whether or not the predicted productivity is smaller than the overcoming threshold.

After implementation, the productivity of the land is restored in the history of strategies that the land-owner agent has. Adding a new productivity of the applied strategy to the history of the strategies, the land-owner forgets the oldest history of the applied strategies. The number of times that land-owner agent can keep the history of its practices and productivity of each strategy is equal to the size of memory (memory-size) that it has. For choosing a strategy based on the past experiences, the land-owner chooses the one with the higher productivity. Therefore, after several times the strategies with the lower productivity are removed from the past experiences, which are stored in the bag of strategy in the memory of the land-owner agent. This activity is implemented under updating strategy procedure in the model.

Land-owner agent takes action to self-organization if the chosen strategy needs neighbors' cooperation: If the strategy that the land-owner chooses requires neighbors' cooperation the land-owner first checks whether or not it has grouping capacity (i-resiste-to-group?). If it resists to grouping it changes the strategy. If it does not resist grouping the self-organization procedure follows the land-owner's resilience score and resilience status (see Section 4.2.2). In the self-organization procedure, the land-owner agent checks its resilience status to decide whether or not it matches the leading role in taking action for encouraging neighbors for grouping. If the land-owner is resilient-leading(rl), it attempts for making group with neighbors. First, it looks for neighbors with the same resilience qualification and leading capacity to make a group regardless whether or not their strategies need cooperation. While it searches for resilient-owner (r) neighbors who are ready for cooperation and their strategies need neighbors' cooperation. If there are such neighbors it makes a group with them. However, if these neighbors' strategies do not need neighbors' cooperation, the land-owner agent tries to encourage them and it may lead to the grouping. Still, the land-owner agent does not neglect neighbors who are individually resilient with a low chance of cooperation. So, it moves to these neighbors' lands and starts to negotiation with the low possibility of being grouped. However, if the land-owner agent is resilient-owner (r) but not having the leading qualification it positively reacts to the cooperation request by the neighbors with the grouping leading capacities. If there is not such a request, the land-owner agent changes its strategy because the requirement of the strategy for neighbors' cooperation cannot be met. With the lower resilience score, the states of neighbors' resilience affect the land-owner agent's decision about whether it could keep the strategy that needs neighbors' cooperation or it has to change the strategy. However, if the institutional management system is Resilience-building (RB), there is a high possibility that the service-providers help the neighbors and the land-owner agent to make a group and apply the strategy that requires neighbors' cooperation.

Land-owner agent builds its resilience by increasing the knowledge: Increasing knowledge of a land-owner agent does not automatically increase its resilience status (see Section 4.2.2). Besides the current resilience status of the land-owner agent, the management system and the support that it could receive by the service-provider agents as well as the access that it has to the required resources play important role in increasing its resilience status when its knowledge has increased. For example, even though the land-owner agent with the resilient-leading (rl) status increases its knowledge to the level that is more than what is required to implement the chosen strategy and has access to the required resources, it has to consider whether the management system is Controlling or Resilience-building. Under the Controlling Management, this land-owner agent may need to make more efforts with less expectation to keep its resilience status than under the Resilience-building management system. When a land-owner agent with the RL status takes leading actions, the possibility of being grouped with the neighbors and successfully increasing its resilience status is lower than when the institution management system is Resilience-building.

Land-owner agent decides for its affected land unit due to severe disturbances: When a land unit is affected by disturbances it becomes a dead-land. When the land unit of a land-owner agent is affected by disturbances and becomes dead-land, the agent may force to leave the land if it resists change. If the land-owner is ready to challenge, which requires being knowledgeable, having access to required resources, being resilient enough, and owning more than three units of land, it stands to change the land utilization and becomes a successful land-owner regardless under which institutional management it performs. However, if the land-owner agent who is ready to challenge but owns less than three units of land, which is not equipped the land-owner with diverse sources to survive, the probability of surviving becomes less and the possibility that its land unit becomes a dead land increases. Moreover, if its strategy requires neighbors' cooperation, regardless of how many land units it owns, if it has a rl status, it may take action to encourage neighbors who are resilient-cooperating (rc), and if it is not being seen by the service-provider, who is corrupted, it may be able to make a group and save its land and survive. But if it is seen by a corrupted service-provider, it may be forced to stop grouping, which makes the land-owner agent leave the land and let its land stay dead-land. However, with the same status of the land-owner agent, the possibility of surviving and restoring the affected land becomes higher when the management system is the Resilience-building

Land-owner agent updates its resilience status: Each land-owner agent who inherits resilience score (my-resilience-score) updates its resilience score through the decision that it makes and the results that it gets. Some of the decisions and the results of the decisions upgrade the resilience status of the individual agent. When the land-owner agent makes decision that upgrades its land status or makes a group to implement the strategy, it may upgrade its resilience score and when the land unit of a land-owner agent is degraded, or when its group dissolves, the agent's resilience may be degraded. The changes are implemented by adding or subtracting a random number of less than 1 to the resilience score of the agent.

Natural-connector agent decides to network: To connect the land units with the land-degradation-class 4, which represents severe degradation of the land unit, and make a network, if the following condition is applied at the system level, natural-connector agents with ctype 4 start to networking with each other and the network grows following the preferential attachment structure at the system level. The natural-connector agent, which is ready to connect checks if the total number of natural-connector agents with ctype 4 in its radius 2 is larger than the total number of natural-connector agents with ctype 1, ctype 2, and ctype 3. Then, it searches if there is any partnered natural-connector agent in its radius 2 because its preferences is to network with the connected natural-connector agent.

Natural-connector agent decides to release disturbances: When the number of the connections of a natural-connector agent in a network, considering its ecological resilience capacity (my-ecological-resilience) and the threshold of natural-connectors in network is getting larger than the ratio of the network threshold to the maximum number of the links of the network, the disturbances is released and affected the lands and the owners that are in the network (see Section 4.2.2 and Equation 1).

Service-provider agent provides services: The mechanism through which service-provider agents provide service to land units and land-owner agents depends on the institutional management system. However, the service-provider agents follow the same path with different possibility of actions that reflects the organizational rules and regulations.

Under the Controlling Management (CM) system, the service-provider agent works from the center and responds to the request that land-owner agent brings to the attention of the service-provider agent at the center. Under the Resilience-building management (RB) system, service-provider agent is assigned to specific area to provide services. A service-provider agent has to move out of the service-center to visit the land units and land-owner agents to find out their needs and provide services to them at their land units. When a service-provider, who is not corrupted, faces a request, or meets a land-owner agent who needs to be supported to have access to resources, provides the land-owner agent with access to required resources. When the request is to support the strategy that requires neighbors' cooperation, if the service-provider agent has grouping capacity, it supports the grouping with the high possibility and if it does not have such a capacity, it denies such a request.

Service-provider agent communicates within the organizations: each service-providers transfer information within the organization. If a service-provider agent who is not corrupted notices a corrupted service-provider it reports to the manager. If the service-provider agent who is corrupted notices a corrupted service-provider, it may join the corrupted agent and make a group of corrupted service-providers. The corrupted grouped service-provider agent checks if the institutional manager is corrupted and number of corrupted services providers is more than total number of service-provider agents, if so, it takes action to confiscate the land of individual to whom it provides services. This reduces the number of lands that the individual owns and if it owns just one land unit the individual is forced to leave its land.

Service-provider agents' numbers increase or decrease: The strategic targets under two institutional management systems are programed in the sub-model of number of service-provider increases or decreases. The strategic targets are the thresholds for increasing or decreasing the number of service-providers. The number of service-providers increases until the strategic target is reached. Then, the number of service-providers decreases, but it does not go less than the number at the starting point. In this model, based on the nature of the institutional management system, specific strategic target is programed for each of them. For the institutional Controlling Management, the strategic target is to increase the total biocapacity of the lands to 400 gha. For the Resilience-building management (RB) system, beside the target that total biocapacity reaches to 400 gha., the system resilience status should be Resilient (R), according to Figure 12.

Even though the response of the service-providers to the disturbances depends on the management system, under the both management systems, the number of service-providers decreases if any affected land unit does not remain.

Service-provider agents' special projects and services for the affected or vulnerable land units and land-owners: The services that a service-provider agent can provide for the land units and land- owners that are affected by the disturbances or have been anticipated to be affected are different under two different management systems.

Under the Resilience-building management (RB) system, not only affected land units and land-owners are taken care of, but also special projects are implemented for vulnerable land units and land-owners without increasing number of service-providers. If any affected land unit is observed the service-providers are sent to the affected land to implement projects to restore the affected lands and support vulnerable land-owners. If affected land-owners have less than 2 units of land the service-provider searches for available land nearby and asks affected land-owner agent to move and own that piece of land and start to use it. Anticipating that disturbances have been occurred due to vulnerability of land units and land-owners, to prevent the possible disturbances, service-providers implement projects on severely degraded lands, with degradation class 4 and ready to connect to the network, and to improve the quality of lands by encouraging resilient individuals close to the vulnerable lands to move to those lands and assist land-owners to cooperate with neighbors to save the lands. Moreover, a special project is designed for the not-vulnerable lands to improve their productivity to reach to the strategic target. In this project, three types of assistance are provided for the land-owners if they need any. They are access to required resources, direct financial support, and support neighbors' cooperation. These projects may upgrade the lands' quality and land-owners' resilience score.

Therefore, under the Resilience-building (RB) management system, special projects are implemented by service-providers, which are programed under the procedure sub-model of take-service-providers-resilience-act. These projects include three procedures:

a) helping land-owners with less than 2 land units to find available lands to own;

b) helping land-owners of lands with degradation-class 4 to increase the quality of their lands if there is any land unit with degradation-class 4; and

c) helping the land-owners of the land units with land-degradation-class 3 and 2 to increase the productivity of their lands if the total-bio is less than desired.

Under the Controlling Management system, only one specific project is set to restore the land units that have been already affected. If any affected land unit is observed, a service-provider agent is sent to the affected land. If the service-provider agent is not corrupted it assists the land units to be restored but it may not lead to a serious restoration. If the service-provider agent is corrupted it checks if there are enough corrupted service-provider agents. If there is corrupted service-provider agent it pushes the land-owner agent to move out of its land. Then, the corrupted service-provider with assistant of the other service-provider agents owns the land unit. Therefore, in the Controlling Management system, the attention is on affected land units and as long as the affected land units are not visible providing the special services are stop.

There are two types of outputs at the system level. One type is simply calculated by totaling variables that are changing over time. These are total biocapacity, which is called total-bio, total population, total number of dead lands, and total number of service-providers if the management system is either Controlling (CM) or Resilience-building

(RB). Total biocapacity at the system level is calculated by adding up biocapacity of each land units when the model initialized. However, biocapacity of each land unit is calculated based on the changes of land status, which is a combination of land use type and land degradation that are changing over time. This calculation is explained in Section 4.1.2. In addition, as the model runs, the total-bio is updated when land use type and/or land degradation class of each land unit changes. For example, if the current land use is crop-land, and land-degradation-class of the land unit is 4, the total-bio adds biocapacity for crop land, which is 0.36. Then, the amount of biocapacity for crop land is multiplied (1 - EPC) for land degradation class 4, which is 0.25, and is deducted from the total-bio, as can be seen in this formula:

total-bio = total-bio – ((1- EPC) * biocapacity)

The number of human agents is not always equal to the population and changes in population occur when a land-owner is forced to leave its land or return to the world to start activity when any land unit is available. The number of dead land unis is calculated by adding up the number of land units that have changed to unproductive lands due to severe disturbances or subtracting number of unproductive land units that have been restored. The number of service-providers is calculated simply by adding or subtracting one when the model automatically deploys or withdraws a service-provider. These totals are recorded or plotted each step.

The second type of output at the system level is applied to generate system resilience status (system-resilience-status). When a SES status is Resilient (R), it means that the system can return to its structure and function. In this model, the structure of the system is presented in the number of population that the system can hold. The total productivity of lands of the SES presents the functionality of the system and is reflected in the total-bio. In this model, the system resilience is categorized in 5 levels: Resilient (R), Semi-resilient (SR), Low-resilient (LR), Not-resilient (NR), and Transferred (T). For each of the status a constant combination of structure and functionality of system is conceptualized. For this model, the numbers for each structure and function are assigned based on the basic observations of the model, as demonstrated in Figure 12.

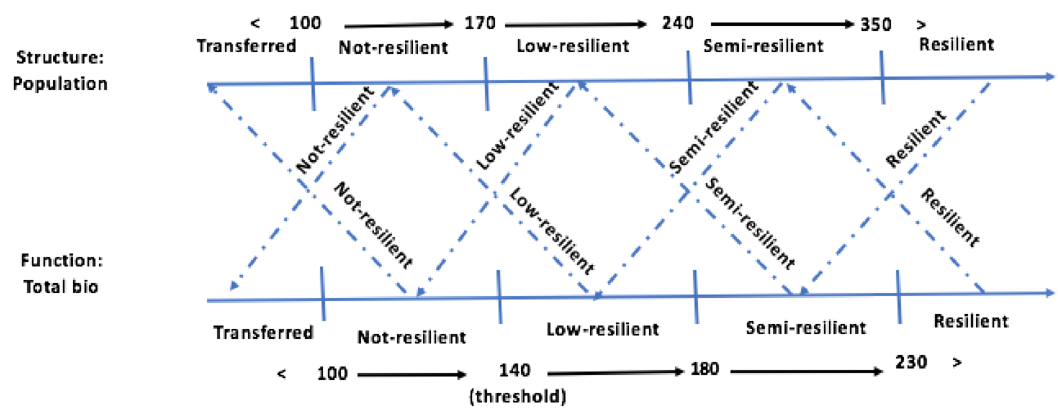

Figure 12. Definition of system resilience status in the model

This Conceptual Definition and related numbers can be read as the following equation:

algorithm. System Resilience Status

Resilient (R):

If the population is equal or above 350 (population >= 350) and the total-bio is equal or above 230 (total-bio >= 230); or

If the population reduces to between 240 and 350 (240 >= population < 350) but total-bio stays at equal or above 230 (total-bio >= 230); or

If the population stays at equal or above 350 (population >= 350) but total-bio reduces to between 160 and 230 (180 >= total-bio < 230)

Semi-resilient (SR):

If the population is between 240 and 350 (240 >= population < 350) and the total-bio is between 160 and 230 (180 >= total-bio < 230); or

If the population reduces to between 170 and 240 (170 >= population < 240) but the total-bio stays between 160 and 230 (180 >= total-bio < 230); or

If the population stays between 240 and 350 (240 >= population < 350) but the total-bio reduces to between 140 and 160 (140 >= total-bio < 160).

Low-resilient (LR):

If the population is between 170 and 240 (170 >= population < 240) and the total-bio is between 140 and 180 (140 >= total-bio <180); or

If the population reduces to between 100 and 170 (100 >= population <170) but the total-bio stays between 140 and 180 (140 >= total-bio < 180); or

If the population stays between 170 and 240 (170 >= population < 240) but the total-bio reduces to between 100 and 140 (100 >= total-bio < 140).

Not-resilient (NR):

If the population is between 100 and 170 (100 >= population < 170) and the total-bio is between 100 and 140 (100 >= total-bio < 140) (threshold); or

If the population reduces to less than100 (population < 100) but the total-bio stays between 100 and 140 (100 >= total-bio <140); or

If the population stays between 100 and 170 (100 >= population < 170) but the total-bio reduces to less than 100 (total-bio <100).

Transferred (T):

If the population and total-bio both reduce to the less than 100 (population < 100 and total-bio < 100).

The system resilience status is one of the major system level output that changes along with the other parameters over time. These changes will be discussed in Chapter Five.

CHAPTER FIVE: THE RESULTS AND FINDINGS

As an abstract model, the generated data by running the model is the source for analyzing the results and findings of the research. The model was run 50 times, each for 1500 timesteps. However, in some cases, which need a longer trend, the model runs for 5000 timesteps. Despite the normative method, as explained in Section 4.2.1, this research explores the resilience of Urmia Lake Basin (ULB) and resilience mechanism through understanding the importance of factors and variables in the process. Thus, the analyzing method applied in this research is a combination of pattern analysis, based on Pattern-Oriented Modeling (Grim, et al., 2005), and parameter analysis (Miller et al., 2010). Applying this method in the process recognizes the influential factors.

This chapter includes three sections. Section 5.1 covers the step-by-step analysis of a sample run of the model for once to understand how the model works and how the parameters affect each other within the process. Section 5.2 presents the findings and results of the system outputs, the pattern analysis of the model for three types of management, and parameter analysis within the process. For this, the model generated data over 50 runs is the data source. Section 5.3 is about the verification, validation, and sensitivity analysis to understand the robustness of the model and the reliability of the results.

5.1 Outputs in the Context of Step-by-Step Process

Learning how the model works is the first step to understand the model's findings and results. For the complexity of the SESs, understanding two mechanisms of how the model works are essential. The first mechanism is how the dynamics at the lower levels generate the evolution of the system's properties. The second is how the individuals' properties change within the nested systems' dynamics. Despite the normative statistic method of identifying the dependent and independent parameters, in this research, the applied analyses method is the parameter analysis within the pattern-based changing process, recognizing the interconnection between levels and the nested dynamic between individuals, collectives, subsystems, and the system properties. Section 5.1.1covers the step-by-step review.

Referring to Section 4.1.2, the model has three agents. In the baseline model and under the No-management system, the service-provider agent does not operate. The land-owner agent locates on the productive land unit, owns and manages it. Besides the locality, the land units have two main attributes that affect the dynamics in the system. Each land unit has the land use type and the land-degradation-class that reflects the quality of the land unit. Moreover, the land use types and land-degradation-class of land units change over time for several reasons, including the decisions that land-owner agents make. The parameter analysis at the system level covers these two parameters. The natural-connector is an ecological agent that locates on the productive land unit. The function of this agent with several attributes is to link land units with specific land-degradation-class, form the ecological network, and hold and release the disturbances. The dynamics between these agents and land units change the properties at the system level. The system resilience status and total-bio are two outputs at the system level that answer the research questions. The parameter analysis includes these two outputs at the system level. This analysis also examines the maximum number of links that the network has. The system-level parameter examination also covers the parameters from the social and ecological subsystems. This investigation covers the resilience status of land-owner agents from the social subsystem and the number of natural-connector agents that release disturbances from the ecological subsystem. In addition to the system-level parameter analysis, the examination covers the main attributes in each subsystem.

Three attributes of natural-connector agents from the ecological subsystem compose and form the selected parameter for system-level analysis. The attribute my-ecological-resilience reflects the inherited resilience capacity. The ctype indicates the type of connection of the agent. The partnered? variable shows whether or not the agent connects to the network. In combination, these reflect how strongly the agent can hold disturbances when there is a growing network (see Equation 1). Therefore, parameter analysis investigates the ecological capacity of the natural-connector agent to release disturbances when it is in the network, which is the left side of Equation 1. When the number of links of a natural-connector agent in the network increases while it has a strong my-ecological-resilience, it could hold the disturbances. In other words, the number of natural-connector agents in the network that release disturbances in one way reflects the low resilience capacity of the natural-connector agent when it is in the network. Therefore, the number of natural-connector agents in the network that releases disturbances is the parameter of the ecological subsystem at the system level. In addition, the maximum number of links of the natural-connector agents shows the high connectivity and pressure of disturbances that flows through the network.

Even though the resilience status of the land-owner agent is inherited, it changes over time for the changes that occur in the other attributes that the agent has. These attributes are whether grouped?, access-to-requited resources, my-land-num, and knowledgeability. The parameter inquiry within the social subsystem examines these attributes to find out how the changes in these attributes affect the resilience status of the land-owner agent. Section 5.1.2 elaborates in parameter analysis.

The management system is a part of the social subsystem of the SESs. However, for its importance, the parameter analysis at the system level covers it in a separate subsection, which is Subsection 5.1.3.

5.1.1 How the Model Works: The Outputs

This section presents the information generated by step-by-step running the baseline model with the No-management system. At each step, the changes are observed and compared with the previous step. Besides learning about the model, the objective is to find the tipping points at the system level. When the model starts at the setup, all the 1058 land units are productive. At the starting point, each land unit randomly receives a land-use type and one of the four classes of the land-degradation-class attribute, which are slight, moderate, severe, and very severe. Also, each natural-connector agent receives one of the four types of connector (ctype), one of the four classes of my-ecological-resilience, and negative response to the attribute of partner?. The model starts with one link, and none of the productive land units is ready to connect through the natural-connector agents and form the network. None of the natural-connector agents releases disturbances either. The total population is 400 individuals who are land-owner agents. Each land-owner agent owns one unit of productive land and receives a random number between 0 and 100, representing my-resilience-score of the agent. As explained in Section 4.2.2, the resilience status of land-owner agents is one of the four grouped states based on the my-resilience-score. Thus, the resilience status of each land-owner agent could be one of the low-resilient (lr), resilient-owner (r), resilient-cooperating (rc), and resilient-leading (rl). At the starting point, each land-owner agent positively or negatively receives the capacity attribute of grouping with the neighbors, but none of the agents has grouped yet. The knowledge of a land-owner agent could be more than the required knowledge at the system level. Also, there is no dead-land, which represents the affected productive land units by disturbances. The system resilience status is Resilient (R), and the total-bio is 284.96 gha.

Table 6 presents the variables/attributes of the land units, agents, and system outputs at the starting point. Figure 13 shows the main variables.

Table 6. Attributes of Land Units, Agents, and the System's Outputs at TS0

Land Units Variables/Attributes (Timesteps = 0)

Variables/Timesteps	Timesteps 0
num-land units with crop land use	632
num-land units with grazing land use	162
num-land units with forest land use	48
num-land units with fishing land use	128
num-land units with built-up land use	88
num-land units with ldc1: slight	264
num-land units with ldc2: moderate	258
num-land units with ldc3: severe	256
num-land units with ldc4: very severe	280
num-land units ready to network[23]	0
num-land units affected by disturbances: dead-land	0

Land-Owner Agent Properties (Timesteps = 0)

Variables/Timesteps	Timesteps 0
num-land-owner agents	400
num-land-owner agents with grouped? = true	0
num-land-owner agents with my-land-num = 0	0
num-land-owners with my-land-num = 1	400
num-land-owner agents with my-land-num = 2	0
num-land-owner agents with my-land-num =3	0
num-land-owner agents with my-land-num = 4	0
num-land-owner agents with my-land-num = 5	0
num-land-owner agents with my-land-num >= 6	0
num-land-owner agents not-resilient (nr)	0

[23] See Figure 8

Variables/Timesteps	Timesteps 0
num-land-owner agents low-resilient (lr)	96
num-land-owner agents resilient-owner (r)	117
num-land-owner agents resilient-cooperating (rc)	148
num-land-owner agents resilient-leading (rl)	39
num-land-owner agents with my-knowledgeability >= knowledge-required	136
num-land-owner agents-with my-knowledgeability < knowledge-required	264
num-land-owner agents with i-have-access-to-required-resources? = true	0
num-land-owner agents with i-have-access-to-required-resources? = false	400

Natural-connector Agents and Links Attributes (Timesteps = 0)

Variables/Timesteps	Timesteps 0
num-natural-connectors-release-disturbances[24]	0
maximum-links	1

System Outputs (Timesteps = 0)

Outputs/Timesteps	Timesteps 0
System resilience status	R
total-bio	284.96

[24] Number of natural connectors that meet the condition of releasing disturbances according to Equation 1: ((num- my-links / (my-ecological-resilience * agent-in-network-ecological-threshold)) >= (network-ecological-threshold / (max [count link-neighbors] of natural-connectors))

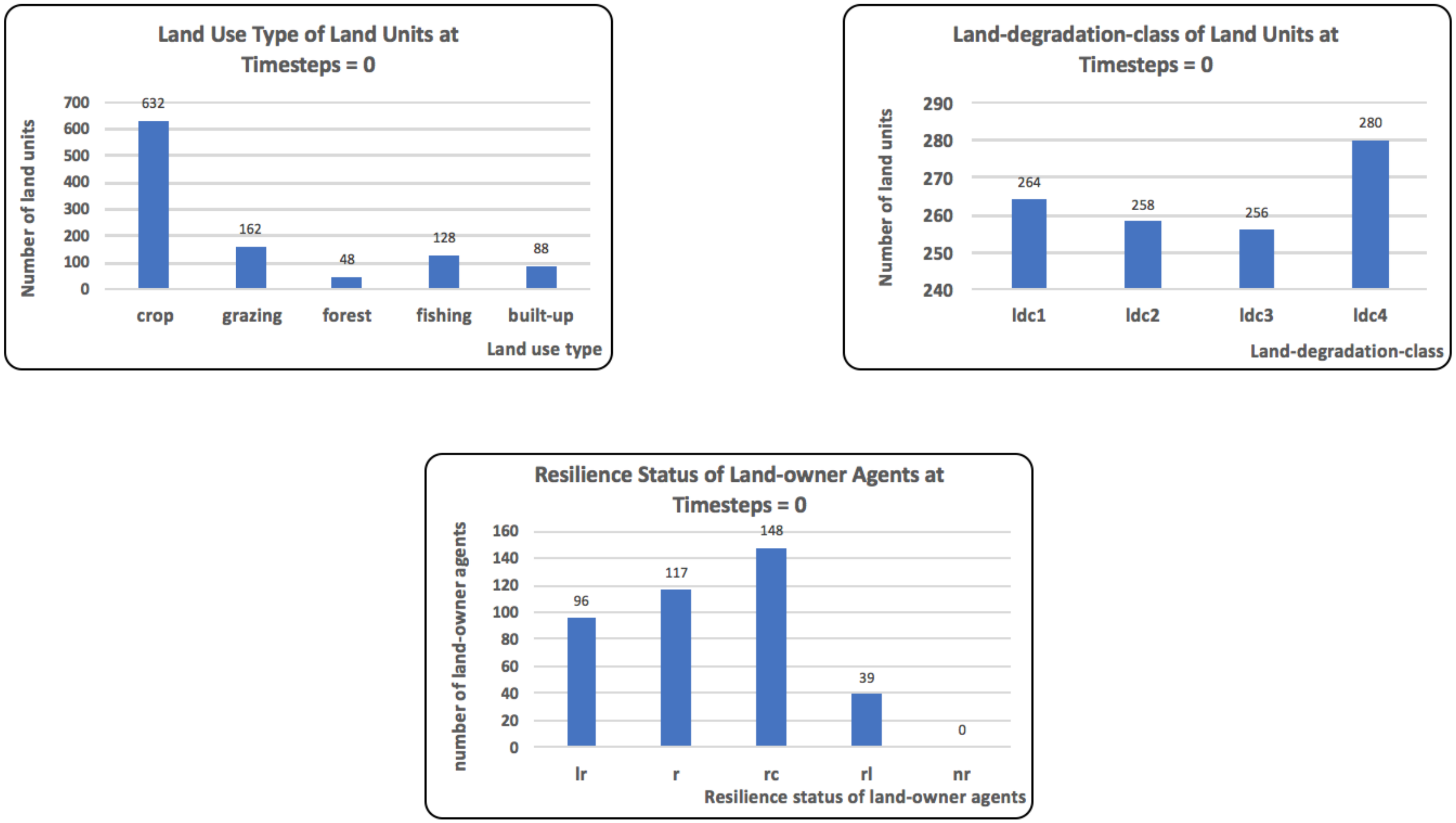

Figure 13. Land use types, land-degradation-class of land units, and resilience status of land-owner agents at TS0

When the model runs one step (timesteps = 1), the following changes occur:

1) the number of land units with the cropland use type decrease by 71, and all other types of land use increases, the grazing land use type units by 17, forest land units by 25, fishing grounds by 14, and built-up by 15 land units.

2) the number of land units with land-degradation-class = 1 (slight) and land-degradation-class = 2 (moderate) increase by 37 and 32 units, respectively, and the number of land units with land-degradation-class = 3 (severe) and land-degradation-class = 4 (very severe) decrease by 43 and 21 units.

3) the number of land units that are ready to make network increases from 0 to 92. This change indicates that some of the land use strategy changes by the land-owner agents affect positively and improve the land-degradation-class of land units. Simultaneously, the connectivity of the neighboring land units with severe and very severe land-degradation-class negatively affects each other and making natural-connector agents getting ready to network.

4) the number of land-owner agents who own two land units increases from 0 to 197, and the number of land-owner agents who own one land unit decreases from 400 to 203.

5) the number of grouped land-owner agents with their neighbors increases from 0 to 40.

6) the resilience status of land-owner agents changes mildly. The numbers of land-owner agents who are low-resilient (lr) and resilient-cooperating (rc) increase by 1.

7) the total-bio decreases less than 20 gha.

These changes at this step (timesteps = 1) explain that some of the land-owner agents apply different strategies that somehow improve the status of their land units, including the land-degradation-class and the land use type. Even though total-bio decreases, the land-degradation-class of land units improve. Implementing the strategies that require grouping with the neighbors, the efforts to make grouped at this step may reflect the role of the grouped parameter to keep the system resilient and the resilience status of the land-owner agents at the setup level. However, the severe degradation of the land units (land units with land-degradation-class = 4 and 3) affects the land units of the neighbors, making the land units getting ready to connect through natural-connector agents and make the network.

Table 7 compares these variables at timesteps 0 and 1. The changes are compared and presented in Figure 14.

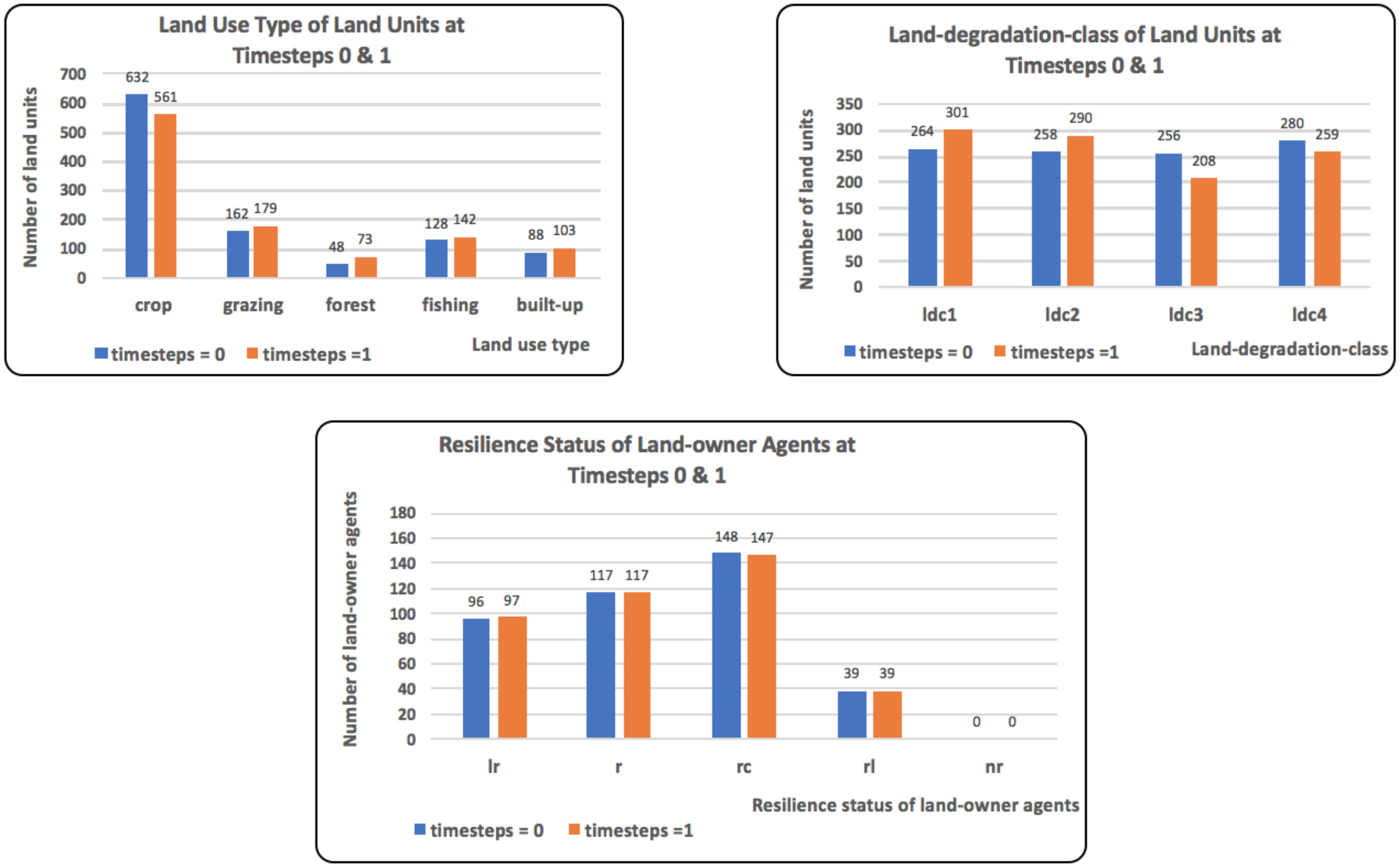

Figure 14. Comparing land use types, land-degradation-class, and resilience status of land-owner agents at TS0, TS1

Table 7. Attributes of Land Units, Agents, and the System's Outputs at TS0 and TS 1

Land Units Variables/Attributes (Timesteps: 0 & 1)

Variables/Timesteps	**Timesteps 0**	**Timesteps 1**
num-land units with crop land use	632	561
num-land units with grazing land use	162	179
num-land units with forest land use	48	73
num-land units with fishing land use	128	142
num-land units with built-up land use	88	103
num-land units with ldc1: slight	264	301
num-land units with ldc2: moderate	258	290
num-land units with ldc3: severe	256	208
num-land units with ldc4: very severe	280	259
num-land units ready to network	0	92
num-land units affected by disturbances: dead-land	0	0

Land-Owner Agent Properties (Timesteps: 0 & 1)

Variables/Timesteps	**Timesteps 0**	**Timesteps 1**
num-land-owner agents	400	400
num-land-owner agents with grouped? = true	0	40
num-land-owner agents with my-land-num = 0	0	0
num-land-owner agents with my-land-num = 1	400	203
num-land-owner agents with my-land-num = 2	0	197
num-land-owner agents with my-land-num =3	0	0
num-land-owner agents with my-land-num = 4	0	0
num-land-owner agents with my-land-num = 5	0	0
num-land-owner agents with my-land-num >= 6	0	0
num-land-owners not-resilient (nr)	0	0
num-land-owner agents low-resilient (lr)	96	97

Variables/Timesteps	Timesteps 0	Timesteps 1
num-land-owner agents resilient-owner (r)	117	117
num-land-owner agents resilient-cooperating (rc)	148	147
num-land-owner agents resilient-leading (rl)	39	39
num-land-owner agents with my-knowledgeability >= knowledge-required	136	136
num-land-owner agents with my-knowledgeability < knowledge-required	264	264
num-land-owner agents with i-have-access-to-required-resources? = true	0	0
num-land-owner agents with i-have-access-to-required-resources? = false	400	400

Natural-connector Agents and Links Attributes (Timesteps: 0 & 1)

Variables/Timesteps	Timesteps 0	Timesteps 1
num-natural-connectors-release-disturbances[25]	0	0
maximum-links	1	1

System Outputs (Timesteps: 0 & 1)

Outputs/Timesteps	Timesteps 0	Timesteps 1
System resilience status	R	R
total-bio	284.96	264.57

[25] Number of natural connectors that meet the condition of releasing disturbances according to Equation 1: in which ((num-my-links / (my-ecological-resilience * agent-in-network-ecological-threshold)) >= (network-ecological-threshold / (max [count link-neighbors] of natural-connectors))

Comparing the properties of the land units, agents, and links at the first two timesteps with the same properties at the starting point, contributes to the learning of what dynamic changes at the lower level of ecological and social subsystems generate the changes at the system level. For the ecological subsystem, two properties of natural-connector agents and links are effective in this nested hierarchy dynamic. As the land-degradation-class, which reflects the quality of the land unit, is the basis for the land-owner agent decision, and the decision affects the land-degradation-class, the attribute of land-degradation-class could be a parameter. The resilience status of the land-owner agent reflects the inherent resilience and what it gains over the times and by the experiences. Therefore, my-resilience-score could be the property of land-owner agents. Table 8 presents the variables and attributes at the starting point and the first two steps and comparing them. Figure 15 compares the changes in the main variables.

Table 8. Attributes of Land Units, Agents, and the System's Outputs at TS0, TS1, and TS2

Land Units Variables/Attributes (Timesteps: 0, 1, & 2)

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2
num-land units with crop land use	632	561	529
num-land units with grazing land use	162	179	175
num-land units with forest land use	48	73	80
num-land units with fishing land use	128	142	156
num-land units with built-up land use	88	103	118
num-land units with ldc1: slight	264	301	326
num-land units with ldc2 moderate	258	290	278
num-land units with ldc3 3: severe	256	208	178
num-land units with ldc4: very severe	280	259	276
num-land units ready to network	0	92	120
num-land units affected by disturbances: dead-land:	0	0	0

Land-Owner Agent Properties (Timesteps: 0, 1 & 2)

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2
num-land-owner agents	400	400	400
num-land-owner agents with grouped? = true	0	40	46
num-land-owner agents with my-land-num = 0	0	0	0
num-land-owner agents with my-land-num = 1	400	203	101
num-land-owner agents with my-land-num = 2	0	197	203
num-land-owner agents with my-land-num =3	0	0	96
num-land-owner agents with my-land-num = 4	0	0	0
num-land-owner agents with my-land-num = 5	0	0	0
num-land-owner agents with my-land-num >= 6	0	0	0
num-land-owner agents not-resilient (nr)	0	0	0
num-land-owner agents low-resilient (lr)	96	97	99
num-land-owner agents resilient-owner (r)	117	117	116
num-land-owner agents resilient-cooperating (rc)	148	147	146

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2
num-land-owner agents resilient-leading (rl)	39	39	39
num-land-owner agents with my-knowledgeability >= knowledge-required	136	136	136
num-land-owner agents with my-knowledgeability < knowledge-required	264	264	
num-land-owner agents with i-have-access-to-required-resources? = true	0	0	0
num-land-owner agents with i-have-access-to-required-resources? = false	400	400	400

Natural-connector Agents and Links Attributes (Timesteps: 0, 1 & 2)

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2
num-natural-connectors-release-disturbances[26]	0	0	0
maximum-links	1	1	1

System Outputs (Timesteps: 0, 1 & 2)

Outputs/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2
System resilience status	R	R	R
total-bio	284.96	264.57	257.30

[26] Number of natural connectors that meet the condition of releasing disturbances according to Equation 1: in which ((num-my-links / (my-ecological-resilience * agent-in-network-ecological-threshold)) >= (network-ecological-threshold / (max [count link-neighbors] of natural-connectors))

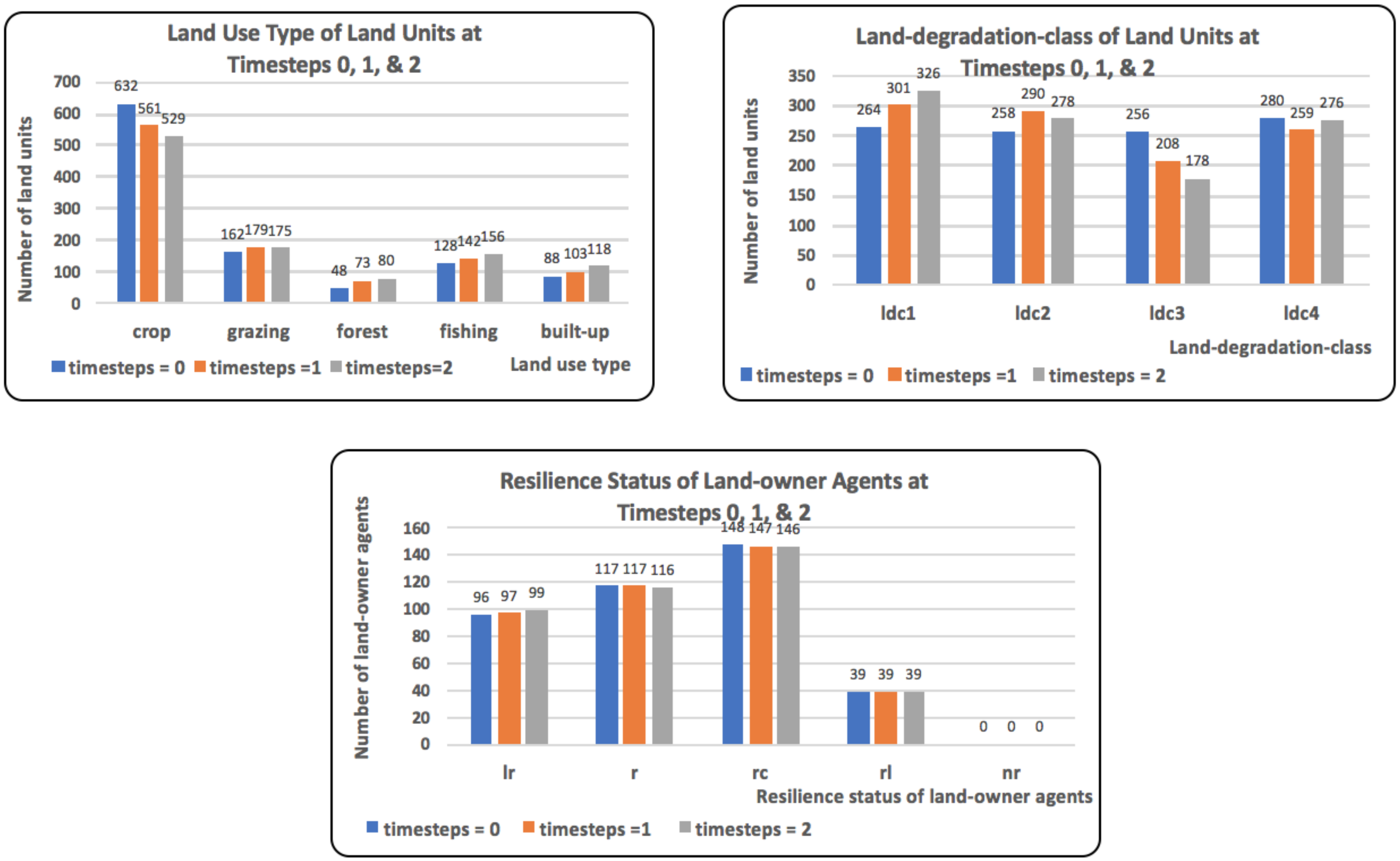

Figure 15. Comparing land use types, land-degradation-class, and resilience status of land-owner agents at TS0, TS1, and TS2

Step-by-step comparing the generated data reveals that the main changes in the properties of the system emerge at the timesteps 6, even though some of the changes gradually occurred in the previous steps. For example, at timesteps 6, the max-links of the natural-connector agents increase to 21 links while the network formed at timesteps 3 with 11 max-links. In the same way, the first natural-connector agent in the network that could release disturbances, according to Equation 1, emerges at timesteps 5. But, the system effect appears one step later. Therefore, timesteps 6 is a tipping point when the properties of the system, which are the system resilience status and total-bio, respectively change to the Semi-resilient and 224 gha. Table 9 shows the parameters over the six timesteps, and Figure 16 presents the changes of the main parameters.

Table 9. Attributes of Land Units, Agents, and the System's Outputs at TS0-TS6

Land Units Variables/Attributes (Timesteps: 0, 1, 2, 3, 4, 5, & 6)

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2	Timesteps 3	Timesteps 4	Timesteps 5	Timesteps 6
num-land-units with crop	632	561	529	499	471	463	473
num-land-units with grazing	162	179	175	187	185	180	170
num-land-units with forest	48	73	80	99	98	109	113
num-land-units with fishing	128	142	156	156	170	166	163
num-land- units with built-up	88	103	118	117	134	140	139
num-land-units with ldc1	264	301	326	326	321	315	311
num-land-units with ldc2	258	290	278	272	266	255	250
num-land-units with ldc3	256	208	178	172	155	152	138
num-land-units with ldc4	280	259	276	288	316	336	350
num-land-units ready- to-network	0	92	120	132	160	169	173
num-land-units-affected-by-disturbances: dead-land:	0	0	0	0	0	0	9

Land-Owner Agent Properties (Timesteps: 0, 1, 2, 3, 4, 5, & 6)

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2	Timesteps 3	Timesteps 4	Timesteps 5	Timesteps 6
num-land-owner agents	400	400	400	400	400	400	400
num-land-owner agents with grouped? = true	0	40	46	56	58	60	61
num-land-owner agents with my-land-num = 0	0	0	0	0	0	0	0
num-land-owner agents with my-land-num = 1	400	203	101	61	55	55	55
num-land-owner agents with my-land-num = 2	0	197	203	135	116	116	116

Variables/Timesteps	Timesteps 0	Timesteps 1	Timesteps 2	Timesteps 3	Timesteps 4	Timesteps 5	Timesteps 6
num-land-owner agents with my-land-num =3	0	0	96	159	152	152	152
num-land-owner agents with my-land-num = 4	0	0	0	45	70	70	70
num-land-owner agents with my-land-num = 5	0	0	0	0	7	7	7
num-land-owner agents with my-land-num >= 6	0	0	0	0	0	0	0
num-land-owner agents not-resilient (nr)	0	0	0	0	0	0	0
num-land-owner agents low-resilient (lr)	96	97	99	99	99	100	103
num-land-owner agents resilient-owner (r)	117	117	116	116	116	115	112
num-land-owner agents resilient-cooperating (rc)	148	147	146	146	146	146	145
num-land-owner agents resilient-leading (rl)	39	39	39	39	39	40	40
num-land-owner agents with my-knowledgeability >= knowledge-required	136	136	136	136	136	136	136
num-land-owner agents with my-knowledgeability < knowledge-required	264	264	264	264	264	264	264
num-land-owner agents with i-have-access-to-required-resources? = true	0	0	0	0	0	0	4
num-land-owner agents with i-have-access-to-required-resources? = false	400	400	400	400	400	400	396

Natural-connector Agents and Links Attributes (Timesteps: 0, 1, 2, 3, 4, 5, & 6)

Variables/Timesteps	**Timesteps 0**	**Timesteps 1**	**Timesteps 2**	**Timesteps 3**	**Timesteps 4**	**Timesteps 5**	**Timesteps 6**
num-natural-connectors-release-disturbances[27]	0	0	0	0	0	1	1
maximum-links	1	1	1	11	18	20	21

System Outputs (Timesteps: 0, 1, 2, 3, 4, 5, & 6)

Outputs/Timesteps	**Timesteps 0**	**Timesteps 1**	**Timesteps 2**	**Timesteps 3**	**Timesteps 4**	**Timesteps 5**	**Timesteps 6**
System resilience status	R	R	R	R	R	R	SR
total-bio	284.96	264.57	257.30	254.18	238.37	230.29	224.2

[27] Number of natural connectors that meet the condition of releasing disturbances according to Equation 1: in which ((num-my-links / (my-ecological-resilience * agent-in-network-ecological-threshold)) >= (network-ecological-threshold / (max [count link-neighbors] of natural-connectors))

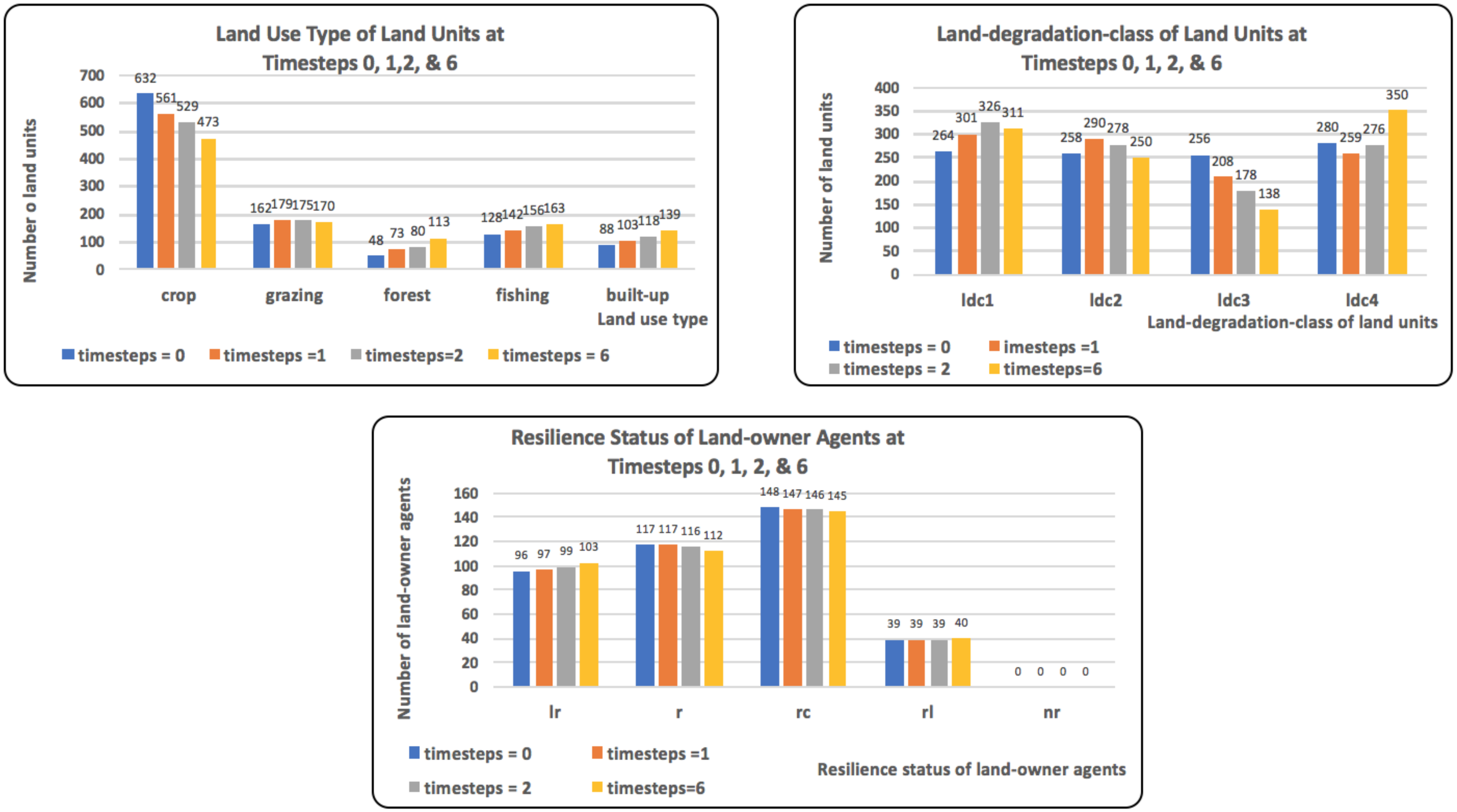

Figure 16. Comparing land use types, land-degradation-class, and resilience status of land-owner agents at TS0, TS1, TS2, & TS6

Continuing step-by-step observation shows a gradual change until timesteps 6 when suddenly a shift at the system level emerges. Also, the system resilience status changes from Resilience (R) to Semi-resilience (SR). Since then and for the 1500 timesteps, the system resilience status stays at the SR state. Therefore, timesteps 6 is a tipping point of shifting regime at the system level, which requires an explanation about how this happens and why it stays at this level. At the individual level, the earliest change appears at timesteps 2, when the number-of-land-units-ready-to-network increases from 0 to 92. This increasing change continues until timesteps 6, at the point that the number of affected land units by disturbances changes from 0 to 9. What explains this change is the appearance of the first natural-connector agent in the network that releases disturbances at timesteps 5, and the effect appears at timesteps 6. **Error! Reference source not found.** compares the main changes at the starting point and timesteps 1, 2, and 6.

The parameter of max-links of the network changes rapidly and reaches 11 links at timesteps 3. The consecutive numbers of max-links from timesteps 4 to 8 are 18, 20, 21, 26, and 29. The parameter remains at 29 over the entire running model for 1500 timesteps. Meanwhile, the parameter of the number of natural-connector agents that release disturbances, which is 0 at the starting point, reaches the maximum number of 2 through the model running. At the timesteps 6, in which the system resilience status shifts to Semi-resilient (SR), while the number of max-links is 21, the number of natural-connector agents that release disturbances is 1. This low number shows that natural-connector agents are resilient enough to hold the disturbances. Even though maximum max-links increase to 29 through the entire running model for 1500 timesteps, the system resilience status does not change. Also, at the starting point, the numbers of land units with different land-degradation-class are close to each other, and the number of land units with land-degradation-class 4 is the lowest number among them. At timesteps 4, the numbers of land units with land-degradation-class 4 increase about 60, the numbers of land units with land-degradation-class 3 decrease more than 120 units, and the numbers of land units with land-degradation-class 1 and 2 increase around 80 units. Still, the number of land units with land-degradation-class 1 is the highest among the total land units. These changes show that the strategies of land-owner agents in the first four timesteps positively affect and improve the quality of land units. Even though around 50% of the land units are ready to connect and form the network and potentially release the disturbances, the number of land units as the affected land units by disturbances still is 0.

Some changes occur in the properties of the land-owner agents. Still, it is hard to accept that timesteps 6 is the tipping point for this agent, considering that the population stays the same and the agents keep their activities. Regarding the resilience status of land-owner agents, the numbers of land-owner agents with the lr and rl (two poles of the resilience status) states slightly increase while the numbers of land-owner agents with r and rc (middle resilience status) slightly decrease. As presented in

Table 9, the resilience status of land-owner agents at the starting point shows that the numbers of land-owner agents who are resilient-owner (r and rc) are higher than the agents with low-resilient (lr) and resilient-leading (rl) state. There are some changes in these numbers at timesteps 5, in which the numbers of land-owner agents with rl and lr mildly increase and the numbers of land-owner agents with r and rc decrease. Still, the portion of land-owner agents with r and rc resilience status remains high. At the starting point, the numbers of land-owner agents with r and rc are more than 250% of the numbers of the land-owner agents with lr and rl state. At timesteps 5, this portion changes to 220%. These changes show the tendency to the polarizing land-owner agents, but having the high numbers of land-owner agents in the middle may affect the system to keep its resiliency at the SR status. In the same way, access to required resources slightly changes, but it does not present a tipping point. Generally, the outputs of this model reflect the following characteristics:

1) the natural-connector agents are ecologically resilient,

2) even though the chosen land use strategies over the four timesteps by the land-owner agents improve the quality of land units, the numbers of land units with land-degradation-class 1 and 4 increase at timesteps 4. The numbers of the land units with different land-degradation-class show the tendency to the polarization. Still, the numbers of land units with the moderate and severe land-degradation-class are high. The status of land-degradation-class of land units at the starting point may have affected the resilience process of the system.

3) A combination of resilience status of the land-owner agent, especially at the middle level of r and rc, may affect the system resilience status to keep the Semi-resilient (SR) status for the entire running for 1500 timesteps.

5.1.2 System Level Outputs and the Relevant Parameters

After learning how the system works and how the attributes change over time, the model runs once for 1500 timesteps to analyze the parameters. In this analysis, shifting the system resilience status is the base for parameter analysis. In other words, when the system variable of system resilience status shifts from one system to the other, it presents a tipping point. Then, the investigation covers the observed numbers for parameters at this point. Running the model many times shows that the changes in system resilience status are not the same. At the starting point of timesteps 0, the system resilience status presents the state of Resilient (R). In some of the running, the system resilience status change to the Semi-resilient (SR) over 1500 timesteps, while in the other running the model, they may move to Low-resilient (LR), Not-resilient (NR), and Transferred (T) status. Therefore, out of many times running the model, four different runs are selected, from which each of them presents one of the system resilience status results, including the Semi-resilient (SR), Low-resilient (LR), Not-resilient (NR), and Transferred (T) to a different system. For each of the four runs, the parameters are analyzed and compared in four runs. This combination method of pattern and parameter analysis goes beyond reductionism and presents the complexity of the system.

Table 10, Table 11, Table 12, and Table 13 present variables and parameters for the models that end with SR, LR, NR, and T system resilience status. Table 10 presents the parameters for the model that ends with SR system resilience status, and the explanation is quite similar to the previous one, for which Table 9 covers the attributes and variables.

Table 10. Attributes of Land Units and Agents for the Model that Turns to Semi-resilient Status at TS 4

Variables- Attributes/ Timesteps	Setup	Timesteps 4
System resilience status	R	SR
total-bio	284.96	228.12
population	400	400
max-links	1	1
num-natural-connector-agents-release-disturbances	0	0
num-land-units with ldc1: slight	263	312
num-land-units with ldc2: moderate	257	274
num-land-units with ldc3: severe	287	162
num-land-units with ldc4: very severe	251	310
num-dead-land-units	0	0
num-land--units-ready-to network	0	153
num-land-owner agents not-resilient (nr)	0	0
num-land-owner agents low-resilient (lr)	67	77
num-land-owner agents resilient-owner (r)	134	128
num-land-owner agents resilient-cooperating (rc)	152	147
num-land-owner agents resilient-leading (rl)	47	48
num- land-owner agents with grouped? = true	0	115
num-land-owner agents with access-to-required-resources	0	0

Table 11 shows the parameters of a system that goes through Semi-resilient (SR) and ends with Low-resilient(LR) status. In this run, at timesteps 6, when the system resilience status moves to the Semi-resilient state (SE), the number of max-links is 21 times higher than the previous run (see Table 10). In this run, the max-links ends with 21 links at timesteps 320, when the system resilience status moves to Low-resilience (LR) state, comparing two Table 10 and Table 11. At timesteps 6, one natural-connector agent in the network loses its ecological resiliency and releases disturbances. This change affects nine land units. At timesteps 320, the number of natural-connector agents in the network releasing disturbances increases to 5, which is the highest number of the natural-connector agents that release disturbances and affects 341 land units and changes them to the dead-land units. About land-degradation-class of the land units, the model starts with the domination of land-degradation-class 4. This domination continues through timestep 6 and 320. Even though the number of land units with land-degradation-class 1 increases at timestep 6, it decreases at timestep 320. The numbers of land units with land-degradation-class 2 and 3 comprise more than 94% of land units with land-degradation-class 1 and 4 at the starting point. This percentage moves to around 59 and 43 at timesteps 6 and 320. This change presents the polarization tendency of the land units over the land-degradation-class.

Regarding the resilience status of the land-owner agents, the model starts with the domination of agents with the order of rc (37%), r (29.25%), lr (24%), and rl (9.75). At timesteps 6, the model presents the same order with a slight change, through which it loses 2% of the land-owner agents with r and rc total. At timesteps 320, with the 11% of land-owner agents who are not resilient anymore (nr), the number of land-owner agents with rl increases to 34% of the population, and the total percentage of land-owner agents with r and rc resilience-status is 31% of the population. At timesteps 320, the number of land-owner agents with the lr state decreases to 24% from 26% at timesteps 6. This model supports the assumption that having enough land-owner agents with r and rc at the starting point prevents the system from severe polarization, even though the number of land-owner agents with rl increases massively to include more than three times.

Table 12 and Table 13 present the parameters of land units, land-owner agents, natural-connector agents, and system outputs in two separate models that end up, respectively, with Not-resilient (NR) and Transferred (T) in system resilience status state.

Table 11. Attributes of Land Units, Agents, and the System's Outputs for a Model that Moves to Semi-resilient at TS6 and Low-resilient Status at TS320

Parameters/ timesteps	Timesteps 0	Timesteps 6	Timesteps 320
System resilience status	R	SR	LR
total-bio	284.96	224	158.99
population	400	400	296
max-links	1	21	34
num-natural-connector-agents-release-disturbances	0	1	5
num-land-units with ldc1	264	311	218
num-land-units with ldc2	258	250	157
num-land-units with ldc3	256	138	58
num-land-units with ldc4	280	350	284
num-dead-land	0	9	341
num-land--units-ready-to network	0	173	154
num-land-owner agents not-resilient (nr)	0	0	33
num-land-owner agents low-resilient (lr)	96	103	70
num-land-owner agents resilient-owner (r)	117	112	32
num-land-owner agents resilient-cooperating (rc)	148	145	61
num-land-owner agents resilient-leading (rl)	39	40	100
num- land-owner agent with grouped? = true	0	61	92
num-land-owner agents with access-to-required-resources	0	4	36

Table 12. Attributes of Land Units, Agents, and the System's Outputs for a model that Moves to Semi-resilient at TS24, to Low-resilient at TS 144, and Stabilizes on Not-resilient Status at TS268

Parameters/ timesteps	**Timesteps 0**	**Timesteps 24**	**Timesteps 144**	**Timesteps 268**
System resilience status	R	SR	LR	NR
total-bio	284.96	229.12	154.86	137
population	400	383	259	227
max-links	1	57	59	59
num-natural-connector-agents-release-disturbances	0	8	16	16
num-land-units with ldc1	289	338	236	214
num-land-units with ldc2	263	214	132	111
num-land-units with ldc3	258	84	49	44
num-land-units with ldc4	248	339	189	142
num-dead-land	0	83	452	547
num-land--units-ready-to network	0	174	89	72
num-land-owner agents not-resilient (nr)	0	0	30	23
num-land-owner agents low-resilient (lr)	79	87	41	35
num-land-owner agents resilient-owner (r)	146	120	47	42
num-land-owner agents resilient-cooperating (rc)	138	122	54	43
Num-land-owner agents resilient-leading (rl)	37	54	87	84
num- land-owner agents with grouped? = true	0	87	90	81
num-land-owner agents with access-to-required-resources	0	9	39	37

Table 13. Attributes of Land Units, Agents, and the System's Outputs for a Model that Moves to Semi-resilient at TS 5, to Low-resilient at TS29, Not-resilient at TS 261, and Stabilizes on Transferred Status at TS 330

Parameters/ Timesteps	Timesteps 0	Timesteps 5	Timesteps 29	Timesteps 261	Timesteps 330
System resilience status	R	SR	LR	NR	T
total-bio	284.96	228.34	157.22	120.43	85.98
population	400	400	308	235	168
max-links	1	57	113	114	114
num-natural-connector-agents-release-disturbances	0	3	26	26	26
num-land-units with ldc1	260	317	215	161	115
num-land-units with ldc2	257	251	162	135	90
num-land-units withldc3	257	149	55	36	23
num-land-units with ldc4	284	340	319	226	174
num-dead-land	0	1	307	500	656
num-land--units-ready-to network	0	177	187	119	79
num-land-owner agents not-resilient (nr)	0	0	0	8	15
num-land-owner agents low-resilient (lr)	77	70	68	52	25
num-land-owner agents resilient-owner (r)	124	128	79	39	15
num-land-owner agents resilient-cooperating (rc)	151	156	106	67	27
num-land-owner agents resilient-leading (rl)	48	46	55	69	86
num- land-owner agents with grouped? = true	0	78	87	86	84
num-land-owner agents with access-to-required-resources	0	0	32	34	36

Figure 17 and Table 14 present the results of comparing Table 10, Table 11, Table 12, and Table 13. These comparisons would give a sense of the importance of parameters in the process of resilience. Table 14 compares the max-links and number of natural-connector agents that release disturbances for four types of system–resilience-status states. Increasing the max-links and the numbers of natural-connector agents that release disturbances affect the system resilience status. However, the models that end Not-resilient (NR) and Transferred (T) present different patterns. At the first tipping point, the number of max-links for both cases is the same. The model that has fewer numbers of natural-connector agents releasing disturbances moves further. At the next tipping point, two parameters increase to the level that shifts the system to the Transferred (T) state. It shows that other parameters twinned with the max-links and the number of natural-connector agents that release disturbances. One of them is the timing. The model that ends up with NR reaches its first tipping point with the higher number of natural-connector agents releasing disturbances, which is 8, at timesteps 24. Though, the other model ends up with the Transferred state at timesteps 5. Within four further timesteps, the system that ends the Transferred state reaches 113 max-links with 26 natural-connector agents that release disturbances. The tipping point 2 for the system that stays at the Not-resilience (NR) state is timesteps 144. It shows the importance of not only two parameters of the max-links and the number of natural-connector agents that release disturbances, but also the timing in shifting a system state. If the number of links reaches its full max-links earlier and the number of natural-connector agents that release disturbances becomes a higher number at the early stage of a system, the possibility that the system moves to a lower system-resilience state increases.

Table 14. Numbers of Max-links and Natural-connector Agents Releasing Disturbances (NCRD) at Different Tipping Points of Four Models with Different System Resilience Status

System Resilience Status	TP 1 (SR)		TP2 (LR)		TP3 (NR)		TP4 (T)	
	Max-links	NCRD	Max-links	NCRD	Max-links	NCRD	Max-links	NCRD
SR	1	0						
LR	21	1	34	5				
NR	57	8	59	16	59	16		
T	57	3	113	26	114	26	114	26

Figure 17 shows the changes in the number of land units with land-degradation-class at the timesteps that the system resilience status changes. At the starting point, all four models present the difference in the number of land units and the number of land units with different land-degradation-class. The first question is whether the initial land-degradation-class of land units affects the resilience mechanism. Table 15 shows the percentage of land units with different land-degradation-class at the starting point for each model. Based on this Table, a system turns to the Not-resilient (NR) state while it starts with the highest percentage in the number of land units with land-degradation-class 1. Two models that turn to Low-resilient (LR) and Transferred (T) states start with the highest number of land units with land-degradation-class 4. The model that reaches the Semi-resilient (SR) state begins with a high percentage of land units with land-degradation-class 3. This comparison indicates that the initial land-degradation-class of land units may not solely affect the resilience process. The locality of land units, through which the land units' neighbors interact and communicate with each other, could be an influential parameter. Over time, this parameter could be twinned with land-degradation-class of land units and affect the process of resilience. As Figure 17 shows, over the process of changing the system resilience status in all four models, the number of land units with land-degradation-class 1 stays at a reasonable level. This information may indicate the effect of the decisions that land-owner agents with high resilience scores make. Table 16 shows the percentage ratio of land units with land-degradation-class 1 to the total number of productive land units at the starting point for different tipping points of four models.

Table 15. Percentage of Land Units with Different land-degradation-class (ldc) at the TS0 in Four Models: Each Ends with Different System Resilience Status

System Resilience Status / Land-degradation -class	% Land Units			
	SR	**LR**	**NR**	**T**
ldc1	24.86	24.95	27.32	24.57
ldc2	24.29	24.39	24.86	24.29
ld3	27.13	24.20	24.39	24.29
ldc4	23.72	26.47	23.44	26.84
total	100.00	100.00	100.00	100.00

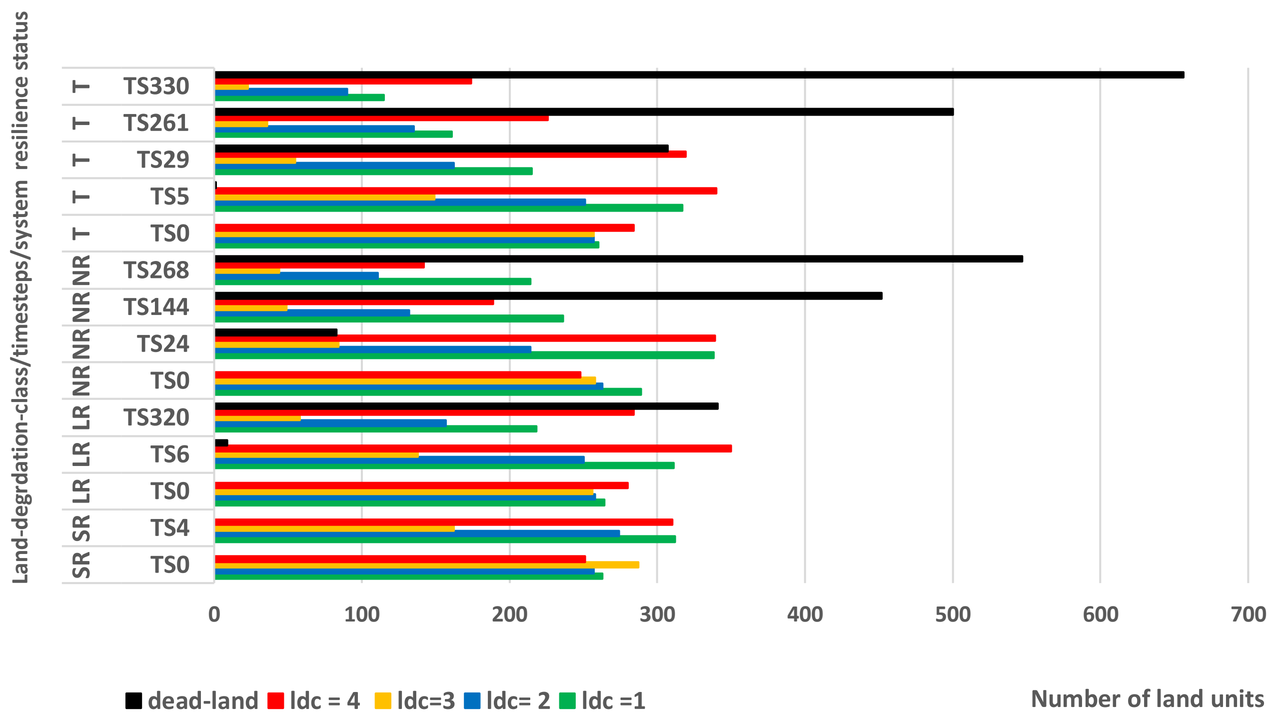

Figure 17. Comparing the numbers of land units with different land-degradation-class at the timesteps that the system resilience status changes (running times: 1, timesteps: 1500)

Table 16. Ratio of Land Units with land-degradation-class 1 in 4 Runs that Lead to different System Resilience Status over 1500 Timesteps

System Resilience Status	Timesteps	%ldc1/total
SR	**TS0**	24.86
SR	**TS4**	29.49
LR	**TS0**	24.95
LR	**TS6**	29.65
LR	**TS320**	30.4
NR	**TS0**	27.32
NR	**TS24**	34.67
NR	**TS144**	38.94
NR	**TS268**	41.88
T	**TS0**	24.57
T	**TS5**	29.99
T	**TS29**	28.63
T	**TS261**	28.85
T	**TS330**	28.61

Figure 18 presents the resilience status of land-owner agents in four models at the tipping points or timesteps that system resilience statuses change. As Figure 18 shows, all four models grant diversity in population for their resilience scores at the starting point. The numbers of land-owner-agents with the middle resilience status, which are resilient-owner (r) and resilient-cooperating (rc), are higher than the other types. The reason is the higher range of possibilities of the randomness for this resilience status category, which is between 21 and 90. The low-resilient (lr) and resilient-leading (rl) categories have a lower range of possibilities of randomness, which are between 0 and 21 for lr, and between 90 and 100 for rl. However, the model that ends up with Semi-resilient (SR) state keeps this diversity without generating any population with Not-resilient (NR) status. As the models move from SR toward T status, they become less diverse while the population with resilient-leading (rl) resilience status grows dominant. The question is whether the resilience status of the population is the output of the system or it is an influential parameter at the starting point of the model. Table 17 shows the resilience status of land-owner agents in four models that end up with different system resilience status. The model that concludes with Semi-resilient (SR) status has an initial lowest number of agents with low-resilient (lr) state and the high number of resilient-owner (r) and resilient-cooperating (rc) in comparison with the other three models. Also, in this model, the initial number of agents with resilient-leading (rl) status is relatively high. However, the distribution of the initial number of land-owner agents in the model that ends with Transferred (T) system resilience status is much closer to the one which concludes with SR status. This description may indicate that a combination of other parameters through the process affects the result of the system resilience status.

Table 17. Resilience Status of Land-owner Agents at TS0 of Four Models

Resilience Status of land-owner Agents	Number of land-owner agents			
	SR	LR	NR	T
lr	67	96	79	77
r	134	117	146	124
rc	152	148	138	151
rl	47	39	37	48

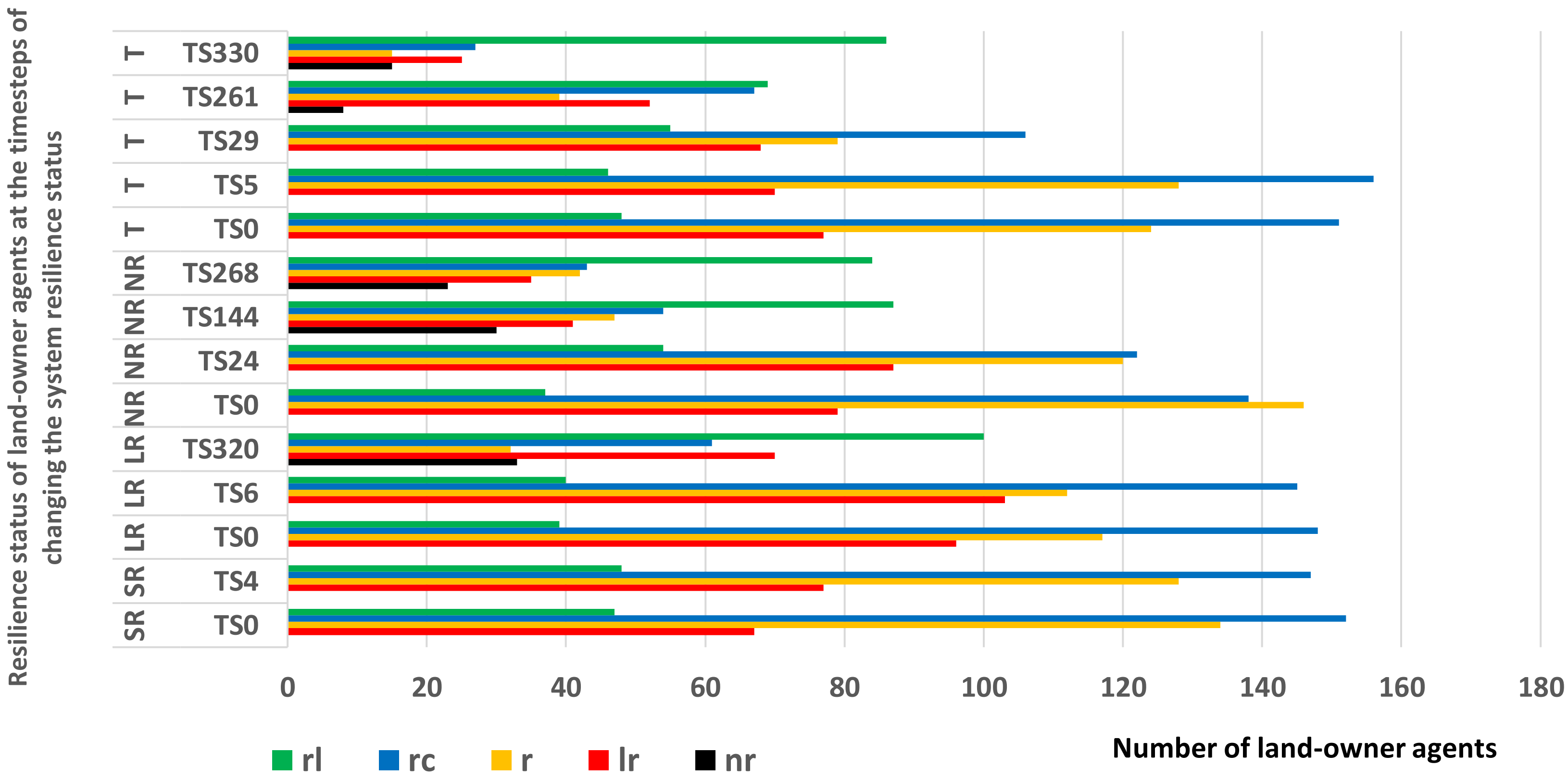

Figure 18. Resilience status of land-owner agents at the timesteps that system resilience status changes (running times:1, timesteps: 1500)

5.1.3 System-level Outputs, Relevant Parameters, and Management System

Running the model 50 times does not produce the same system outputs, including the system resilience status, as explained in Section 5.1.2. Comparing these outputs under three management systems explains the role of management parameters in the resilience mechanism procedure. Figure 19 compares the numbers of different system resilience status that emerge under three management types. Under the Resilience-building (RB) management, system Resilient (R) is the output for all 50 runs. Under the Controlling Management (CM) system, the highest frequency of system resilience status belongs to the Transferred (T) state, which occurs 28 times, but under the No-management (NM) system, the Transferred state appears 3 times out of 50. In the second-highest order, the Not-resilient (NR) status stands that emerges 16 times, however; under the NM, this state appears 23 times. Though none of the model running produces Resilient (R) state, the lowest system resilience status belongs to Semi-resilient (SR), which occurs twice, and the next lowest order belongs to the state of Low-resilient (LR) that appears four times. Under the NM system, Semi-resilient (SR) state occurs 11 times and Low-resilient state (LR) 13 times. Thus, under the C management, the order of emerging the output of the system resilience status is T, NR, LR, and SR, whereas for the NM, the order is NR, LR, and SR.

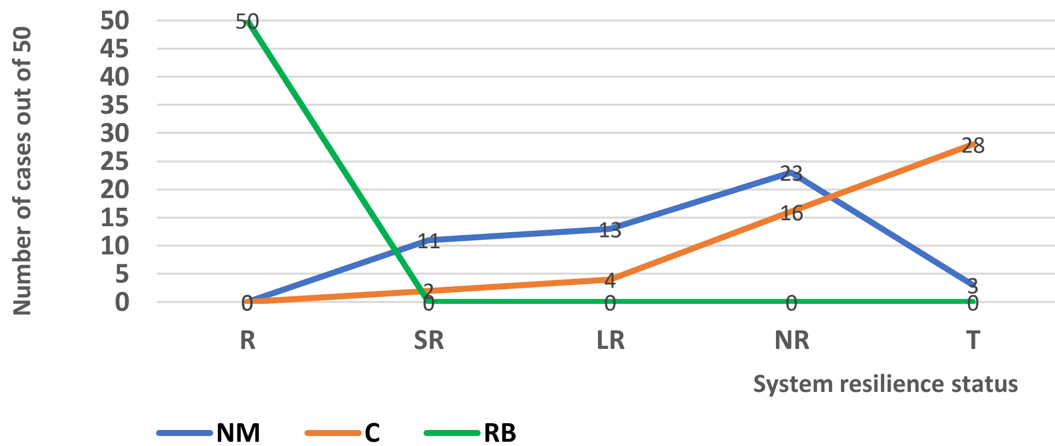

Figure 19. Comparing the possibility of emerging each type of system resilience status under three management systems (average of 1500 timesteps for 50 runs)

The management approach, the method and types of providing services, and the systematic corruption/ or anti-corruption could affect the system level outputs of system resilience status. In this research, two categories reflect the management approach. Whether the management system encourages or prevents the land-owner agents from making the groups, and supports or ignores the vulnerable land units and land-owner agents. The number of service-provider reflects the effectiveness of the method of providing the services. In an ineffective system, the management intends to increase the number of service-providers instead of promoting the quality of service providing. The number of service-providers who own land units indicates whether the management system systematically ignores/ or supports corruption. Comparing the following parameters and data for three types of management system measures how the management systems affect the system resilience status output:

1) Max-links and numbers of natural-connector agents that release disturbances;

2) Number of land units with different land-degradation-class as well as dead-lands;

3) Number of land-owner agents with different resilience status;

4) Number of land-owner agents who work in groups; and

5) Number of service-providers and number of service-providers who own land units.

Running the model 50 times and 1500 are the data sources for comparing the parameters in three management systems at the starting and ending points (timesteps 0 & 1500) and the averages. In combination, this comparison could regulate the impact of the management system on the system resilience status.

Table 18 shows the numbers of max-links and the natural-connector agents that release disturbances (NCRD) under three management systems: No-management (NM), Controlling Management (CM), and Resilience-building (RB) at the starting point (TS0), the ending point (TS1500), as well as the average and the standard deviation. The management approach, method, and the type of services under the Resilience-building prevent the model from developing any network over 1500 timesteps. Under two management systems of No-management (NM) and Controlling Management (CM), the numbers of max-links and NCRD are very close to each other. However, NM performs and functions better than the Controlling Management (CM) system, comparing the numbers of max-links and NCRD at 1500 timesteps, the averages, and the standard deviations.

Table 18. Comparing Numbers of Max-links and NCRD at TS0 and TS1500, the Averages and Standard Deviations under Three Management Systems: NM (Not-management), CM (Controlling), and RB (Resilience-building)

Management System	NM		C		RB	
Parameter	**Max-links**	**NCRD**	**Max-links**	**NCRD**	**Max-links**	**NCRD**
TS= 0	1	0	1	0	1	0
TS = 1500	46	10	54	12	1	0
Average	46	10	52	11	1	0
Standard Deviation	2.63	0.86	4.17	2.21	0	0

Figure 20 compares the system-level outputs of the number of land units with different land-degradation-class under three management systems. Reviewing this Figure indicates that the approach and the method of providing services under Resilience-building (RB) management lead to an increase in the numbers of land units with land-degradation-class 1 and 2 at the timestep1500 in comparison with the starting point (timesteps 0); a reduction in the number of land units with land-degradation-class 3; the elimination of land units with land-degradation-class 4; and the prevention of generating any dead-land units. Under the Controlling Management (CM) and at timestep1500, the reduced number of dead-land units to around 7% and the increased number of land units with land-degradation-class 4 to more than 60 % of the number of productive land units at the starting point reflect the approach and method of providing services. This management system mainly targets the affected land units by disturbances. Under No-management (NM) system, the increased number of the dead-land units at the timestep1500 and the average indicate that the disasters are much greater than the land-owner agents could manage. Still, the number of land units with land-degradation-class 1, at the timesteps 1500 and average is higher than the number of land units with degradation-class 2, 3, and 4, which shows the efforts of land-owner agents to save the quality of land units. Regarding the average number of land units with different degradation classes, the dispersion among individuals and the averages under Resilience-building (RB) is the lowest and under No-management (NM) is the highest, as presented in Table 19.

Table 19. Comparing the Average and Standard Deviation of Number of Land Units with Different Land-degradation-class under Three Management Systems

management system	Land-degradation-class	TS0	TS1500	average	standard deviation
NM	ldc1	273	172	206.68	34.40
NM	ldc2	260	72	96.75	27.19
NM	ldc3	253	34	46.59	13.63
NM	ldc4	272	165	199.52	42.03
NM	dead-land	0	635	525.12	118.62
C	ldc1	264	229	244.37	23.58
C	ldc2	267	164	179.21	19.00
C	ldc3	242	24	35.83	17.63
C	ldc4	285	642	597.85	62.19
C	dead-land	0	72	48.05	14.15
RB	ldc1	272	528	516.41	14.09
RB	ldc2	264	411	413.00	15.24
RB	ldc3	249	115	124.37	9.76
RB	ldc4	273	0	0.18	7.04
RB	dead-land	0	0	0.00	0.00

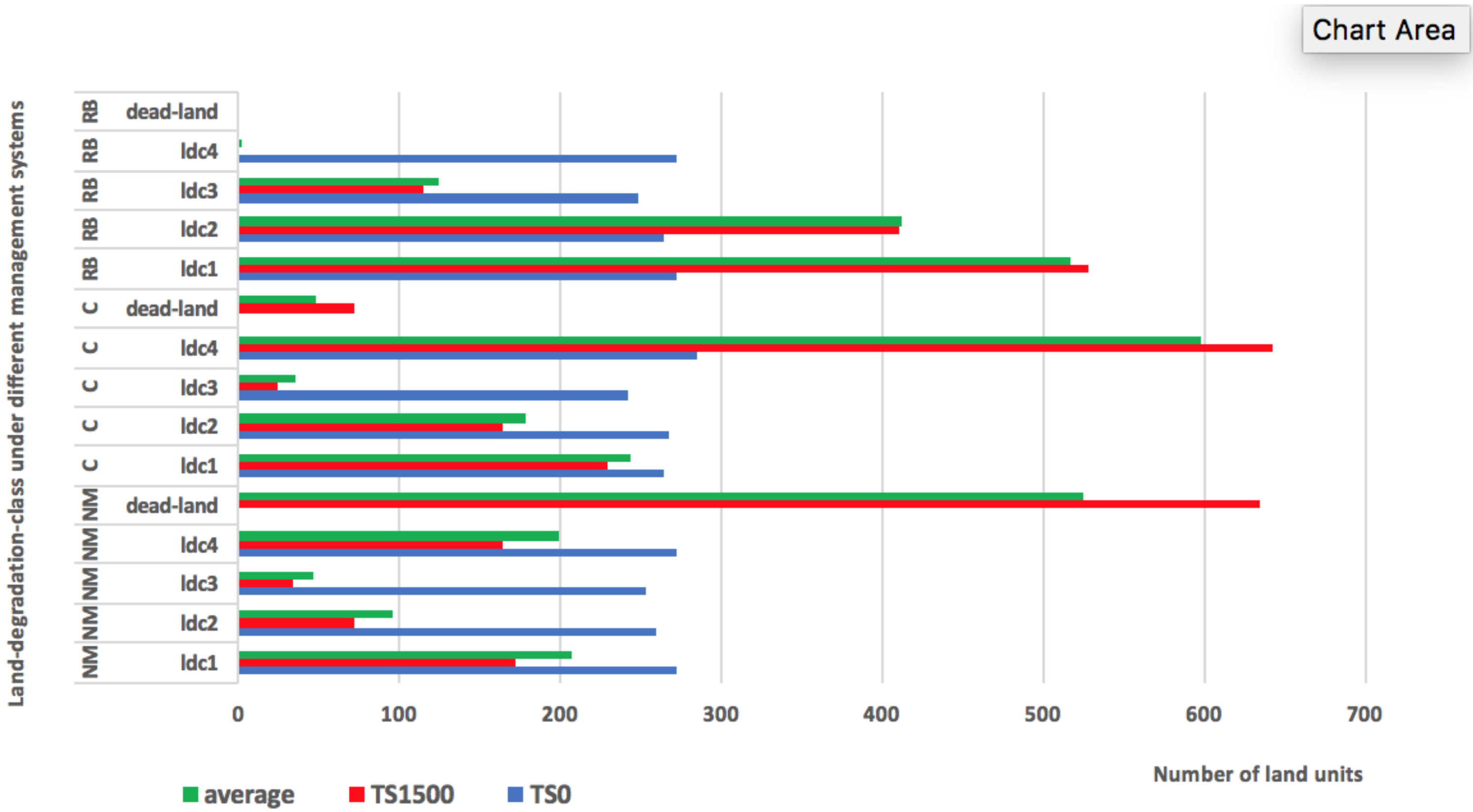

Figure 20. Comparing the number of land units with different land-degradation-class at starting point (TS0), end point (TS1500), and average under three management systems

Figure 21 shows the resilience status of the land-owner agents (my-resilience-status: MRE) at the average level, the starting point (TS0), and the ending point (TS1500) under three management systems. Under Resilience-building management (RB) system, the resilience state of land-owner agents increases to the highest level (rl), and the system prevents anyone from dropping to a state of resilience less than 0 (nr). This descriptive static indicates the comprehensive policy of supporting vulnerable land-owner agents, financially and technically. Under the Controlling Management (CM) system, the number of land-owner agents reduces to ¼ of the initial population. The number of land-owner agents with the resilient-leading state (rl) increases by 3.75% of the initial population. In addition, the number of not-resilient (nr) land-owner agents increases by 5.25% of the initial population. The numbers of land-owner agents with the other states (lr, r, rc) reduce to -17.5%, -34%, and -30.25% of the initial agents with their resilience states. Under the No-management system, the total population at timestep 1500 is 1/2 of the initial population. The number of land-owner agents with the resilient-leading state increases to 10.5% of the initial number of agents with the same resilience state. This management system generates 3.75% of the land-owner agents who are not-resilient (nr). Comparing all these numbers under Controlling Management (CM) and No-management (NM) systems indicates that the polarization is toward agents with the rl status. Also, under the No-management system, the percentages of land-owner agents with lr, r, and rc reduce to fewer numbers than the land-owner agents with the same states under the CM. This information shows that under the Controlling Management (CM) system, polarization becomes greater than under the NM system. Still, the state of rl is dominant.

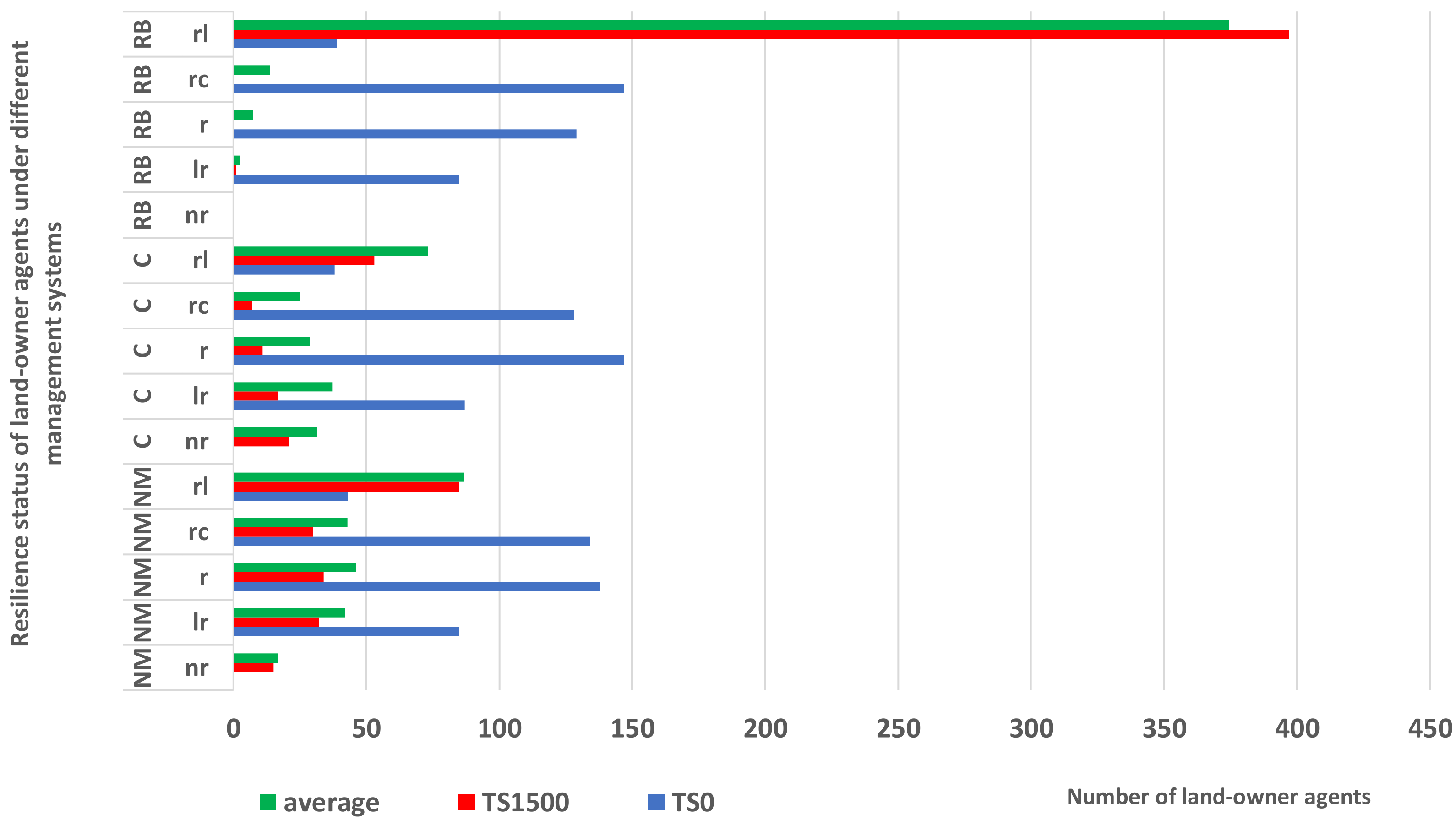

Figure 21. Comparing the status of land-owner agents at the starting point (TS0), ending Point (TS1500), and average under three management systems

Some of the chosen strategies require cooperation and grouping with the neighbors. Some situations prevent the land-owner agents from the group with the neighbors. The land-owner agent cannot group with the neighbors if they do not have the cooperation capacity because of their resilience scores. It decides to change its strategy, which may not be its best choice. Besides the locality and the chance of neighboring with the low capacity grouping neighbors, the policy under the Controlling Management (CM) is to prevent grouping. If the service-provider agents notice any grouping neighbors, they break it. The Resilience-building management (RB) promotes the land-owner agents to the group. Table 20 presents the average percentage of land-owner agents who work in groups under three management systems. As expected, nearly the total population works in the groups under the Resilience-building management (RB) system. Without any governmental intervention, preventing or promoting grouping, under the No-management (NM) system, around 21% of land-owner agents are grouped. Despite the blocking policy under the Controlling Management (CM), the number of grouped land-owner agents is just 2% less than the grouped agents under No-management (NM). This comparison reflects the inefficiency of the Controlling Management (CM) system in implementing the controlling policy. The reasons could be the providing service method, which is from within the service-centers instead of going to the fields, the limited ability to increase the number of service-provider agents, and the domination of corruption in the system. The high standard deviation under both CM and RB systems indicates the effect of the policies.

Table 20. The Average Percentage of Grouped Land-owner Agents under Three Management Systems

Management System	NM	CM	RB
Average %	20.84	18.73	98.34
Standard Deviation	4.80	15.61	18.44

Under both Controlling Management (CM) and Resilience-building (RB) systems, the number of service-provider agents at the starting and the ending points, which are 24 and 71 respectively, as well as the average number, which is 70, and the standard deviation, which is 4.82, are the same. However, under the Resilience-building management (RB), almost the total population work in groups. The average number of land-owner agents working in groups for the No-management (NM) system is about 21% and for the Controlling Management (CM) is about 19% of the total population. These similarities and differences under three management systems for service providing indicate the inefficiency of the preventing grouping policy under the CM system. One of the reasons is the method of providing services from the service-centers. The number of service-provider agents owning land-units reflects corruption. Under the Resilience-building management (RB), this number firmly is 0. Under the Controlling Management (CM) system, the average number of service-providers who own land units is 66 out of the total number of service-provider agents, while the standard deviation is 12. This number starts at 0, ends with 70, which covers the total number of service-provider agents. At the timesteps 1500, the service-provider agents own 705 units of the productive lands, while land-owner agents own 281 units, which is less than 30% of the total land-units.

5.2 The Results and Findings

One of the main outputs of the model is the system resilience status. As discussed in Section 4.3.4 (see Figure 12), the relationships between the structural and functional parameters of population size and total-bio of the productive land units identify the system resilience status. The system resilience status changes over time due to interactions between the lower levels parameters. Section 5.2.1 presents the results of analyzing the changes in the system resilience status over time. Moreover, the variables and attributes and the parameters are the inputs of the model that change over time. These changes at the lower levels of the system indicate how the micro and macro levels of the system affect each other. Out of the system level changing inputs, this Section presents the characteristics of individuals, including resilience score, owning land units, and grouping; the land status, including land degradation class and land use types; and the natural-connectors' links.

5.2.1 System Resilience Status, Structure, and Function

One of the main outputs of the model is the state of the system resilience status. The result of 50 times running the model for 1500 timesteps indicates that the system does not behave the same for each run. Figure 19 shows the number of times that the model presents one of the system-resilience status out of running the model for 50 times under three types of management systems. Under the No-management system, Transferred (T) has the lowest frequency number of emerging times, which is 3, and the highest number, which is 23, belongs to the state of Not-resilient (NR), which is 23. The Low-resilient (LR) with 13, Semi-resilient (SR) with 11, and Resilient (R) with 0 times of appearance as the final state of system resilient status is the order of emerging the outputs over 50 runs for 1500 timesteps.

Understanding the reason that all the 50 times running the model do not lead to the same outputs at the system level, the components of the system resilience status, which are population and total-bio and respectively present the structure and function of the system as explained in Section 4.3.4 and Figure 12, are investigated. One of the reasons of this diverse results is the stochastic and randomness of variables and the applied rules for their interactions. The other reason is the complexity of the SES that is reflected in a nested integrated model instead of integrating the results of the subsystems. This would limit the ability of identifying the parameters without analyzing the paths.

Understanding how system resilience status cannot be predicted, Spaghetti plots of population and total-bio outputs through run by run over 1500 timesteps are presented in Figure 22 and Figure 24.

As Figure 22 presents, each of the 50 model runs starts at 400 population but goes through different declining path, ending between 367 and 121. The lower paths mostly present the Transferred (T) and Not-resilient (NT) state of system resilient status and the paths at the higher level mostly present the Semi-resilient (SR) state of the system resilience status. This is explained more clearly by their average and average moving in Figure 23. However, as Table 21 shows the dispersion within each run is high and as the output of system resilience status moves from Semi-resilient (SR) to the Transferred (T) state, this disparity increases. This indicates that there is a need to analyze pattern analyzing.

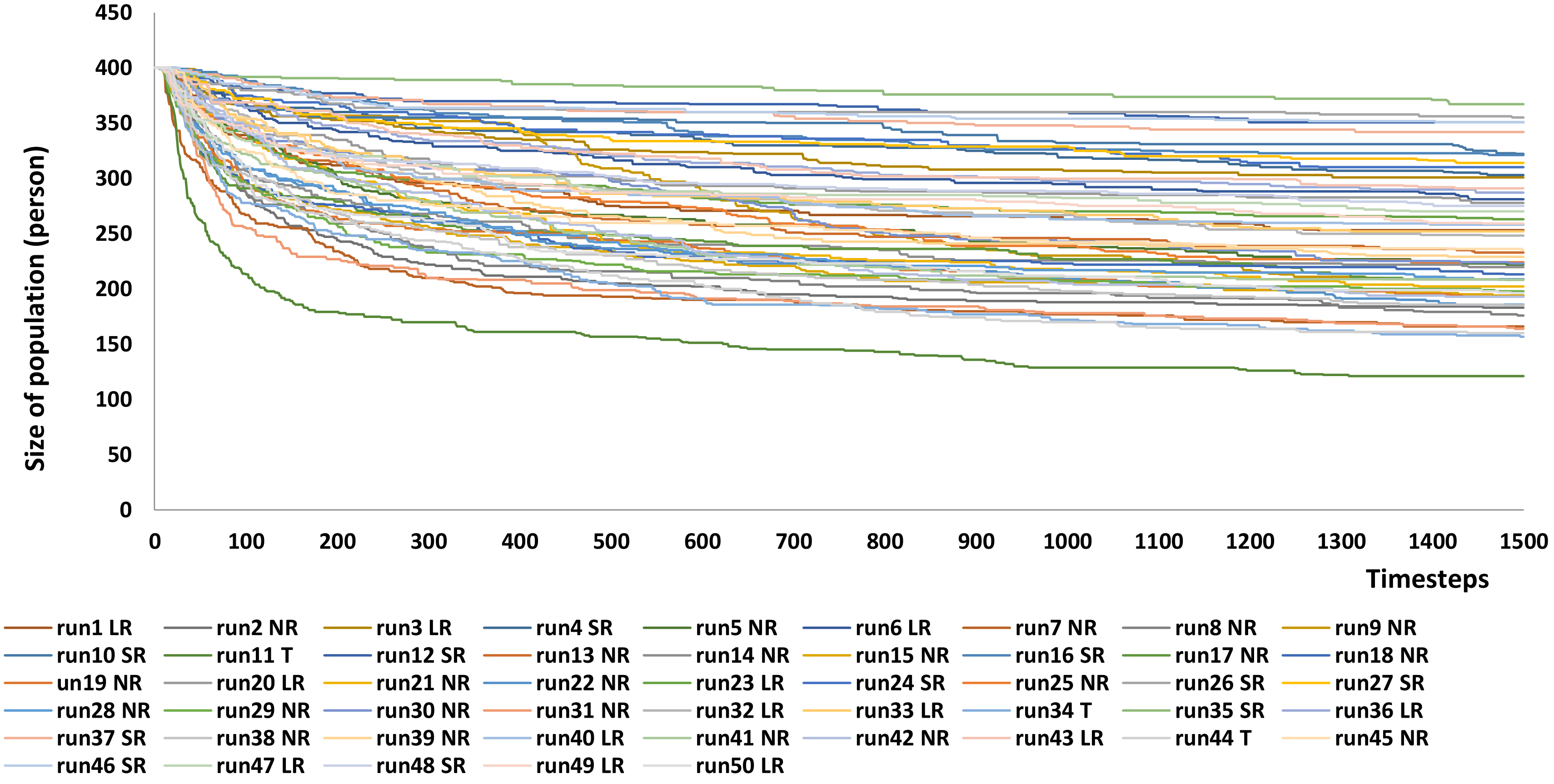

Figure 22. Spaghetti plot of population 50 runs over 1500 timesteps representing system resilience status

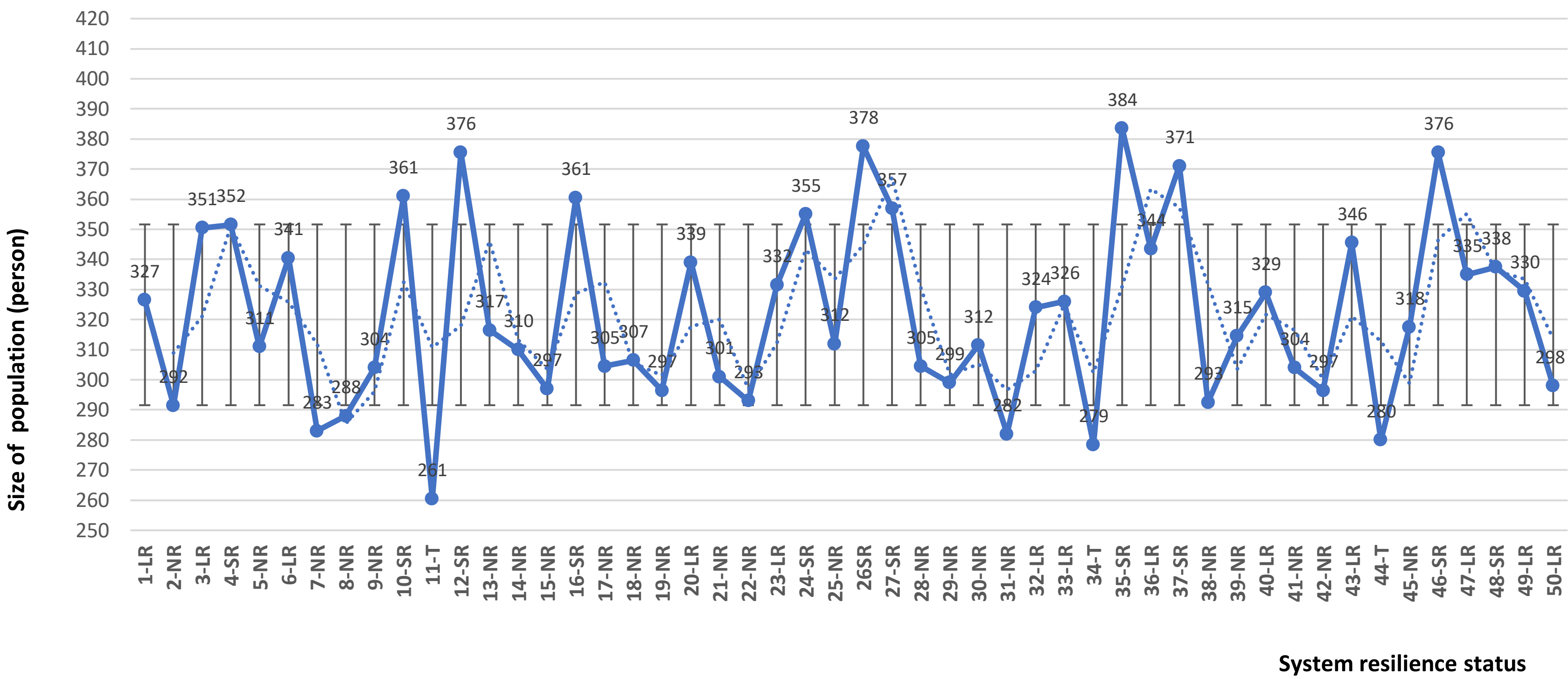

Figure 23. Average of 50 runs of population and moving average of population, representing system resilience status

Table 21. Average Number of Population for Each Run and Standard Deviation

System Resilience Status	Run Number	Average	Standard Deviation
SR	run4	352	49
SR	run10	361	39
SR	run12	376	25
SR	run16	361	40
SR	run24	355	45
SR	run26	378	23
SR	run27	357	43
SR	rn35	384	17
SR	run37	371	29
SR	run46	376	25
SR	run48	338	63
LR	run1	327	74
LR	run3	351	50
LR	run6	341	60
LR	run20	339	61
LR	run23	332	69
LR	run32	324	76
LR	run33	326	74
LR	run36	344	57
LR	run40	329	71
LR	run43	346	55
LR	run47	335	65
LR	run49	330	71
LR	run50	298	102
NR	run2	292	109
NR	run5	311	89
NR	run7	283	117
NR	run8	288	112
NR	run9	304	96
NR	run13	317	84
NR	run14	310	90
NR	run15	297	103
NR	run17	305	96
NR	run18	307	94
NR	run19	297	104
NR	run21	301	99
NR	run22	293	107
NR	run25	312	88
NR	run28	305	96

System Resilience Status	Run Number	Average	Standard Deviation
NR	run29	299	101
NR	run30	312	89
NR	run31	282	118
NR	un38	293	108
NR	run39	315	86
NR	run41	304	96
NR	run42	297	104
NR	run45	318	83
T	run11	261	140
T	run34	279	122
T	run44	280	120

The other system-level output is total-bio. As shown in Figure 24 , each of the 50-model's run produces different system level outputs of total-bio while the amount of total-bio at the starting point for all of them is 284.95 gha. Each of the model's run goes through different declining paths, ending between 214 and 66 gha. The lower paths mostly belong to the model's runs that end with the system resilience status of Transferred (T) or Not-resilience (NT). The paths at the higher level mostly belong to the model's runs that end with the system resilience status of Semi-resilience (SR). This is much clearly shown in Figure 25 , in which the average and moving average of 50 runs over 1500 timesteps are presented.

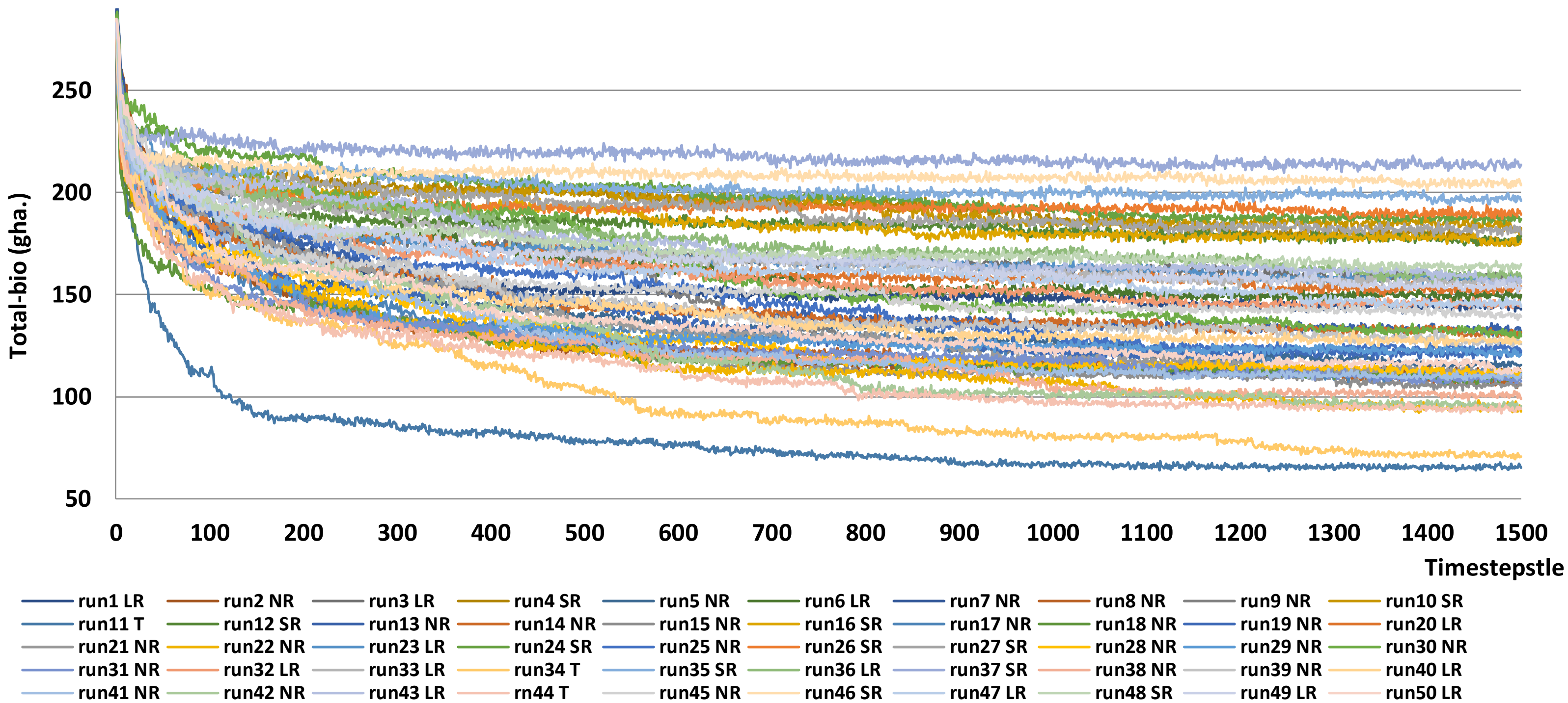

Figure 24. Spaghetti plot of total-bio of 50 runs over 1500 timesteps, representing system resilience status

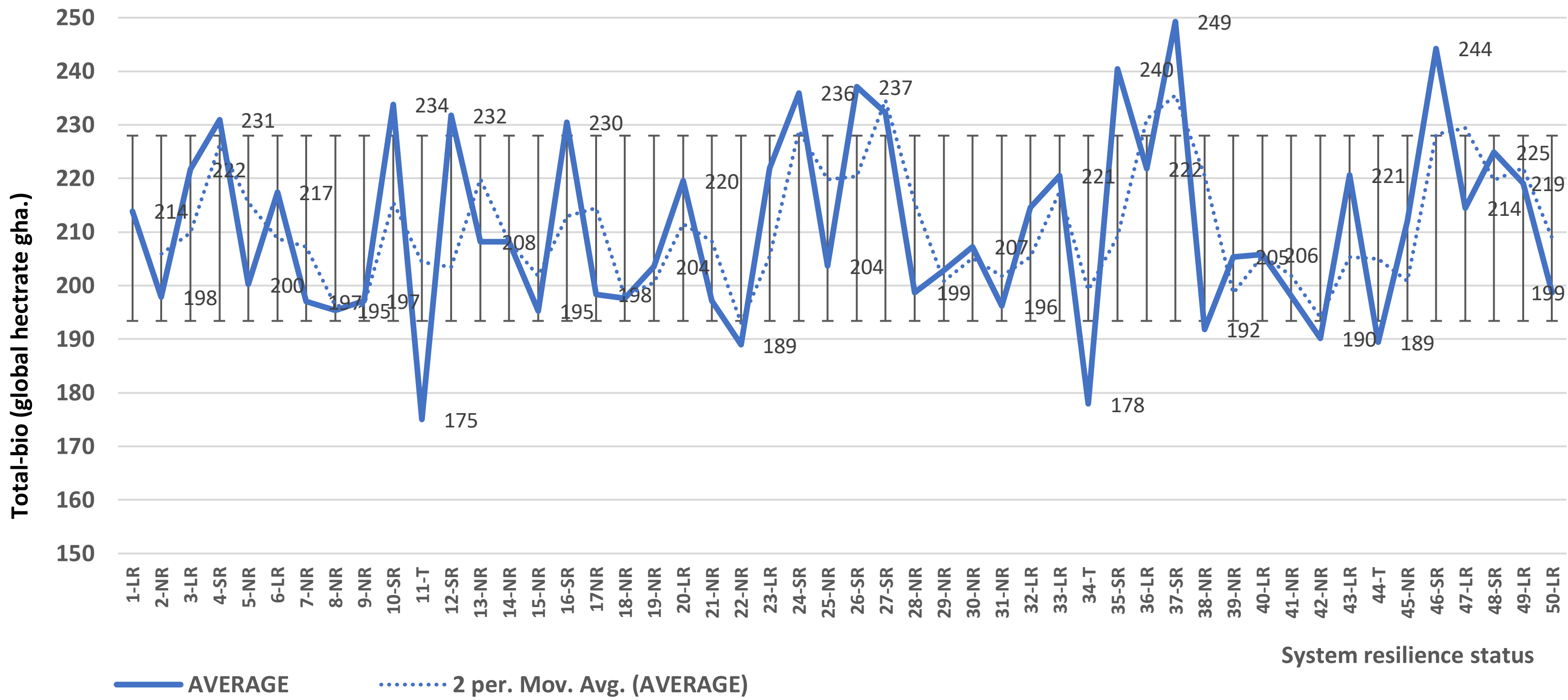

Figure 25. Average of 50 runs and moving average of total-bio over 1500 timesteps

As Table 22 shows the dispersion among each running model for total-bio is high too. It is an indication that the average cannot represent the real changes of total-bio each time that model runs and path dependency presentation would provide better understanding from the changes of total- bio.

Table 22. Average of 50 Runs and Moving Average of total-bio

System Resilience Status	Running Time Number	Average total-bio	STDV
SR	run4	230.91	54.05
SR	run10	233.79	51.17
SR	run12	231.78	53.18
SR	run16	230.49	54.47
SR	run24	235.99	48.97
SR	run26	237.10	47.86
SR	un27	232.24	52.72
SR	rn35	240.44	44.52
SR	run37	249.27	35.69
SR	run46	244.27	40.69
SR	run48	224.88	60.08
LR	run1	213.92	71.04
LR	run3	221.69	63.27
LR	run6	217.43	67.53
LR	run20	219.55	65.42
LR	run23	221.91	63.05
LR	run32	214.58	70.38
LR	run33	220.54	64.42
LR	run36	221.80	63.16
LR	run40	205.82	79.14
LR	run43	220.63	64.33
LR	run47	214.46	70.50
LR	run49	219.12	65.84
LR	run50	198.74	86.22
NR	run2	197.90	87.06
NR	run5	200.21	84.75

System Resilience Status	Running Time Number	Average total-bio	STDV
NR	run7	196.98	87.98
NR	run8	195.38	89.58
NR	run9	197.19	87.77
NR	run13	208.15	76.81
NR	run14	208.19	76.77
NR	run15	195.29	89.67
NR	run17	198.40	86.57
NR	run18	197.69	87.28
NR	run19	203.54	81.42
NR	run21	197.13	87.83
NR	run22	188.93	96.03
NR	run25	203.68	81.28
NR	run28	198.75	86.21
NR	run29	202.85	82.11
NR	run30	207.28	77.68
NR	run31	196.20	88.76
NR	un38	191.85	93.11
NR	run39	205.39	79.57
NR	run41	198.06	86.90
NR	run42	190.13	94.83
NR	run45	212.14	72.82
T	run11	175.03	109.93
T	run34	177.90	107.06
T	run44	189.44	95.52

All these data indicate that the system resilience output has to be understood through changes over time.

5.2.2 System Resilience Status, Structure, and Function Over Time

As explained in Section 5.2.1 it is necessary to analyze the system resilience status, as one of the major results of the model that changes over time due to ecological, social, and political behaviors of its parts. This output is identified in the capacity of a system to return to its structure and function, reflected in population size and productivity of total-bio of land in this model (see Figure 12). Running the model under three types of institutional management of No-management (NM), Controlling Management (CM), and Resilience-building (RB) presents different system resilience status that is respectively shown in Figure 26, Figure 28, and Figure 30.

The result of running the model for the 50 times under the No- management (NM) system, as presented in Figure 19, indicates that the system does not behave the same over the 50 times run. However, Figure 26 presents a pattern of changing system resilience status over 1500 timesteps. At the starting point, the system is resilient (R), but, in less than 50 timesteps, the resilient status of the system drops to 1 and 2 cases out of 50, stays at that level for 40 timesteps while the system moves to the Semi-resilient (SR) state. When the system loses its full Resilient (R) status, the system slowly starts to show the state of Low-resilient (LR), and the state of Semi-resilient (SR) slowly drops. However, the appearance of the Low-resilient (LR) state increases the possibility of the Semi-resilient (SR) state of the system, which drops after the timesteps of around 200, and the Not-resilient (NR) state of the system starts to emerge. A combination of these three states continues to the tipping point, when the state of Not-resilient (NR) takes over the state of Low-resilient (LR) at the timesteps of around 500. At this point, the pattern shows that Semi-resilient (SR) status still is dominant, and Transferred (T) status starts to increase. Then, the Low-resilient (LR) state stays constant while the Not-resilient (NR) status increases and slowly takes over the Low-resilient (LR) status. In the last 500 timesteps, the system presents 4 status with the high domination of Not-resilient (NR) state, the lowest possibility of Transferred (T), increasing slowly the possibility of Low-resilient (LR) state over Semi-resilient (SR). Therefore, the system resilience status under NM presents 4 tipping points. The first one can be identified at the early timesteps when the state of the Resilient (R) drops sharply and Semi-resilient (SR) status increases to the top. The second tipping point is around 500 timesteps when the Not-resilient (NR) state takes over the Low-resilient (LR) state. The third one appears when the Not-resilient (NR) state takes over the Semi-resilient (SR) state after the 800 timesteps. The last tipping point appears when the Low-resilient (LR) state of the system attempts to take over the Semi-resilient (SR) state at the 1400 timesteps.

However, running the model for 5000 timesteps clarifies the further pattern. As shown in Figure 27, even though some differences can be identified in the first steps, two differences are important. First, the system Transferred (T) status takes over Semi-resilient (SR) and Low-resilient (LR) status, which stays lower than Not-resilient (NR) status of the system. Second, the system Low-resilient (LR) status takes over the Semi-resilient (SR) status at the early stage. These differences indicate that the system resilient status is not predictable when there is not any intervention, for example by institutional management system.

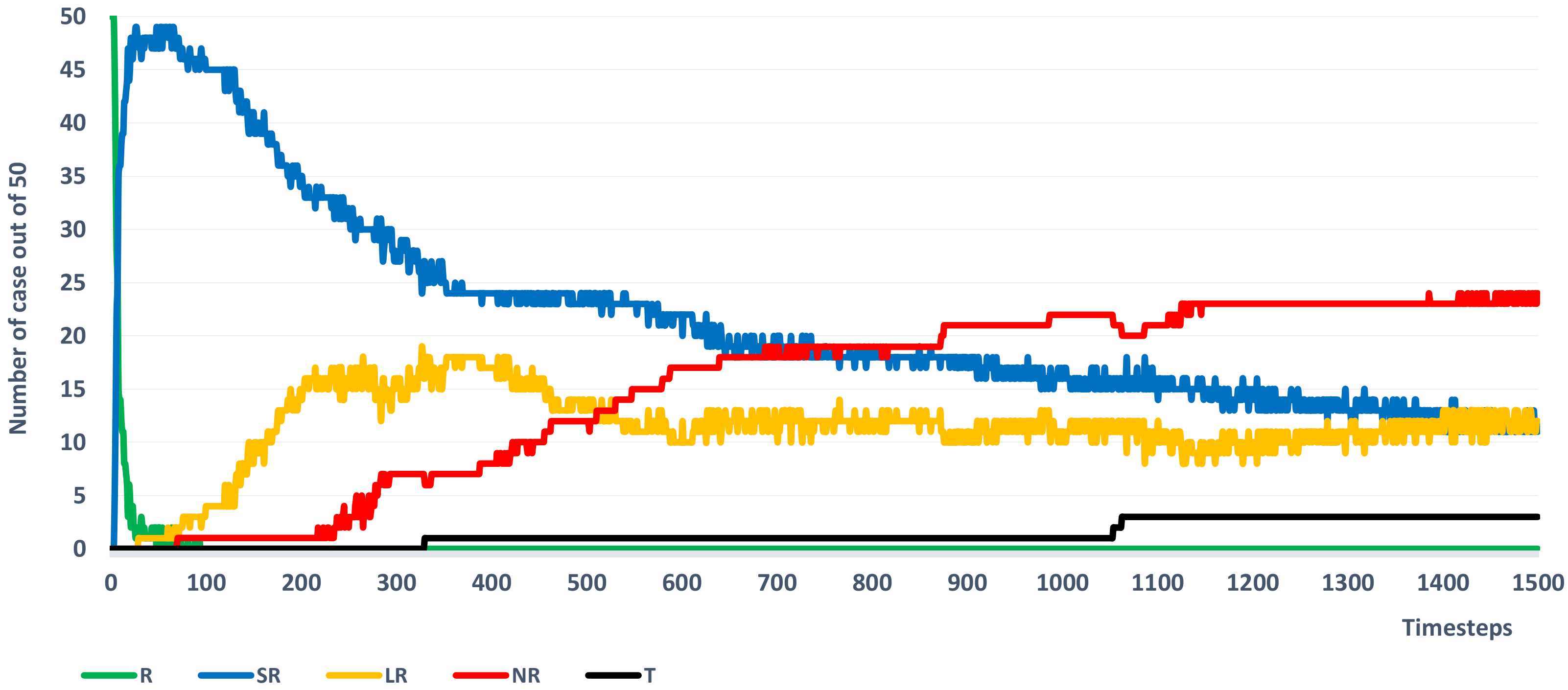

Figure 26. System resilience status under the No-management (NM) system

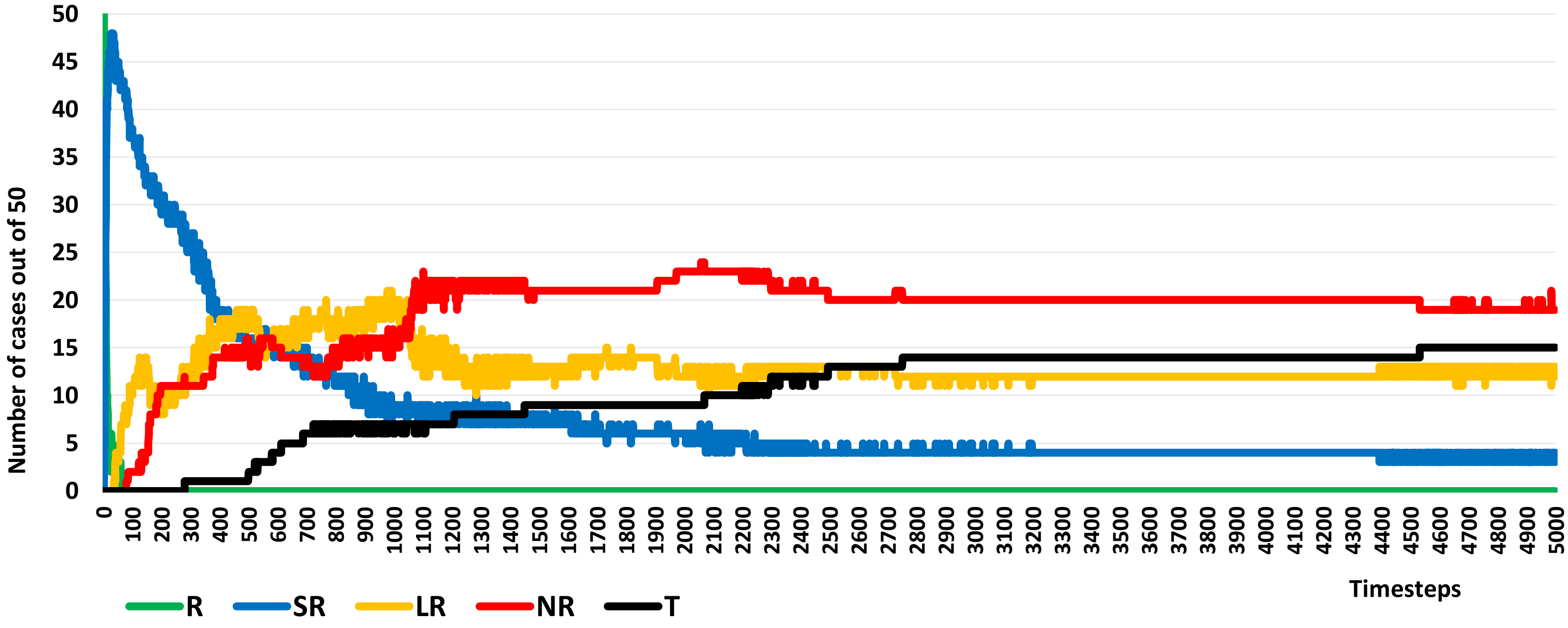

Figure 27. System resilience status under the No-management (NM) system over 5000 timesteps

As Figure 28 shows, under the Controlling Management (CM) system, the resilience status of the system starts by presenting the Resilient (R) state. Even though at the early stage of running the model, the resilient state of the system drops but it does not reach to 1 or 2 until the 100 timesteps. While the state of Semi-resilient (SR) sharply increases at the early stages of running the model, the state of Low-resilient (LR) and consequently Not-resilient (NR) status increases before the timesteps of 100. The state of Transferred (T) emerges slowly when the state of Resilient (R) drops to 1 to 2 and takes over all other system's status at the timesteps of around 450 and its domination possibility continues to increase. This is the major tipping point in which not only Transferred (T) state becomes dominant but also Not-resilient (NR) state crosses over and higher than the Low-resilient (LR) and Semi-resilient (SR) states. The Semi-resilient (SR) state drops to the low possibility of less than 10% and continues, while the competition between two states of Low-resilient (LR) and Not-resilient (NR) finally leads to the state that Not-resilient (NR) takes over.

Total states of the system resilience status under Controlling Management (CM) is presented in Figure 19. As shown in this Figure, while the model presents a Semi-resilient (SR) and Low-resilient (LR) status just 2 and 4 times, respectively, the Transferred (T) and Not-resilient (NR) are the highest status of the system with 28 and 16 times. Running the model under Controlling Management (CM) for 5000 timesteps, which is presented in Figure 29, reveals a very clear domination of transferred (T) state of the system resilience status while the main pattern under 5000 timesteps remains the same as the pattern under 1500 timesteps. This indicates how controlling individuals under the Controlling Management (CM) shapes the pattern.

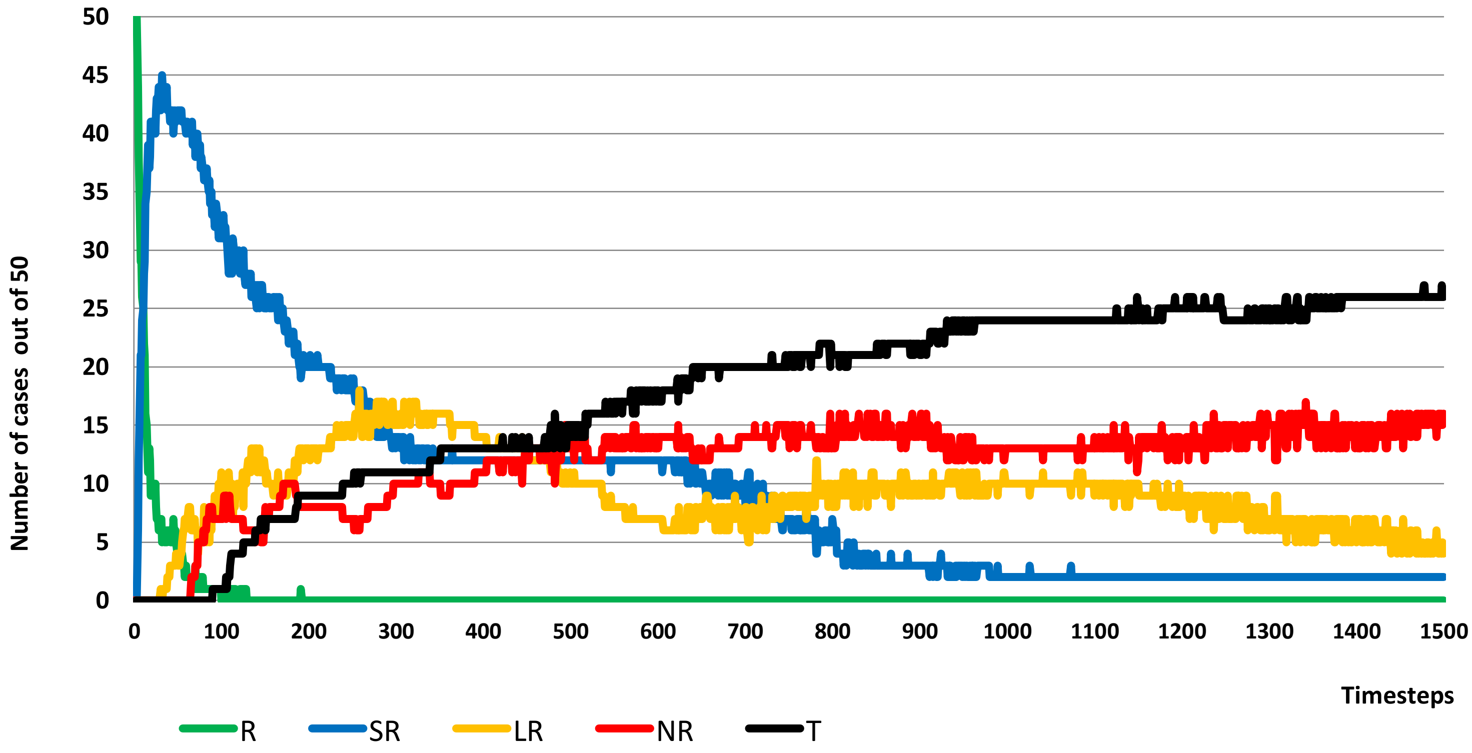

Figure 28. System resilience status under the Controlling Management (CM) system

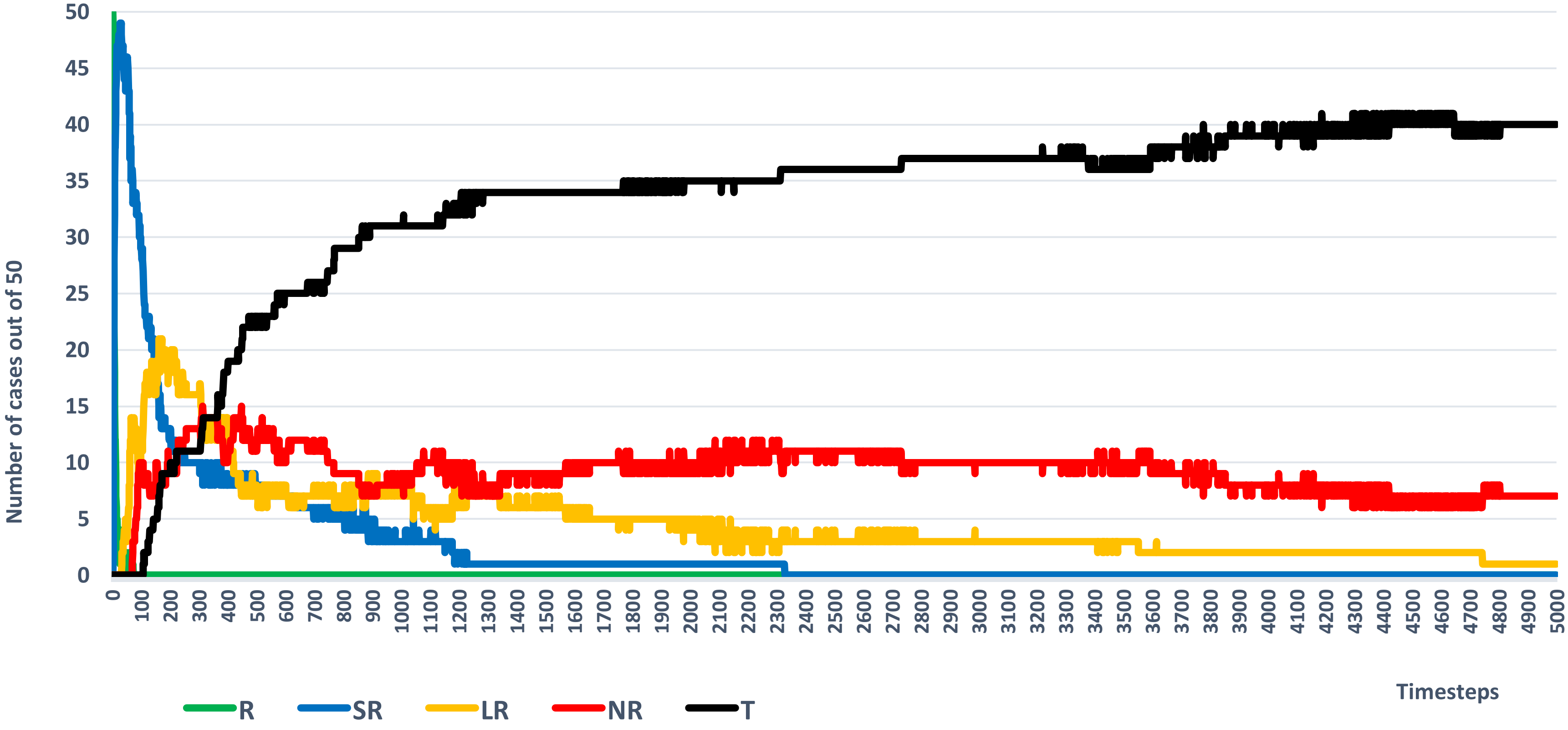

Figure 29. System resilience status under the Controlling Management (CM) system over 5000 timesteps

As Figure 30 shows, under the Resilience-building management (RB), the system demonstrates two types of system resilience status. They are the state of Resilient (R) and Semi-resilient (SR). The model starts with the Resilient (R) state at the highest possible and continues to the end, with a very few times that the state of Semi-resilient (SR) appears, covering less than 5% of running times. This, also indicates how the institutional management system could shape the pattern of the resilience-building of a SES.

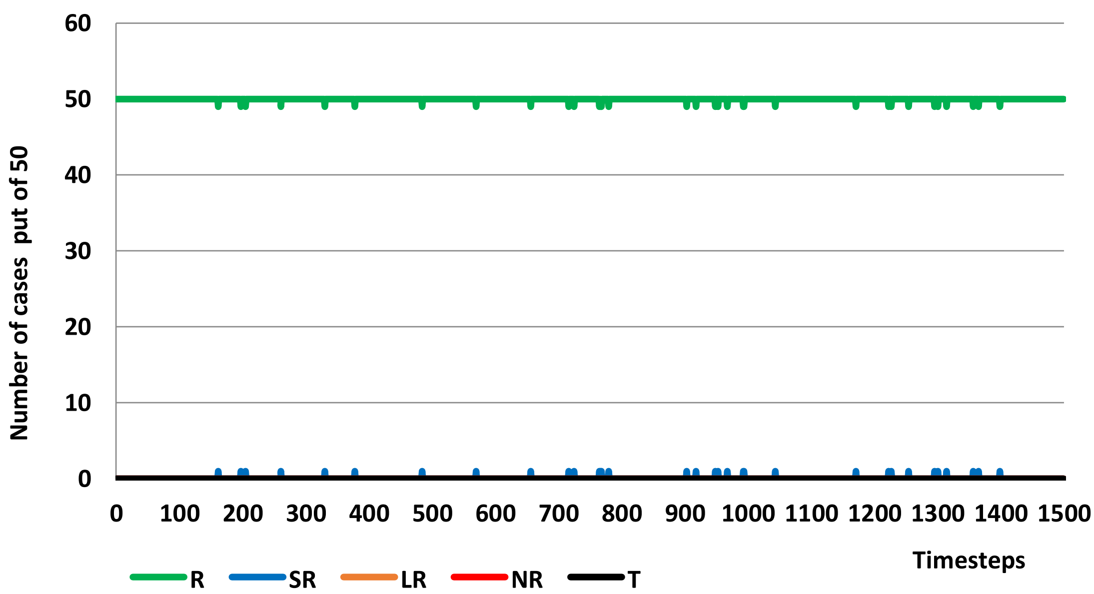

Figure 30. System resilience status under Resilience-building Management (RB) system

Two parameters of population size and total biocapacity (total-bio) justify the changes of the system resilience status. These parameters represent, respectively, the system structure and function of the productivity of land units, as identified in Figure 12. Figure 31, Figure 32, and Figure 33 show the changes in these parameters under three types of the management system. As Figure 31 shows, under No-management institutional management, population size reaches 49% while total-bio covers 40% of their starting numbers. The population size may count as the reason that the system stays in its Not-resilient (NR) state and not Transferring (T).

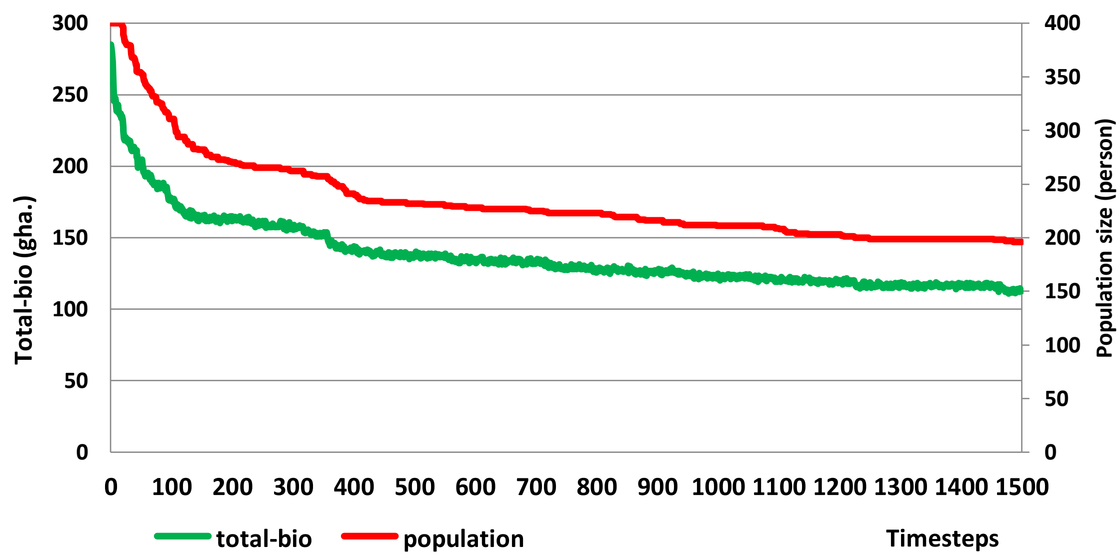

Figure 31. System structure and function: population size and total-bio under the No-Management (NM) system

Changing the population size and total-bio under Controlling Management (CM), Figure 32, indicates that while the total-bio reaches 32% of its starting amount, the population size changes to 27% of its starting size. The population size and total-bio under the Controlling Management (CM) system drop to a lower state than the No-management (NM) system. Under the Resilience-building management (RB) system, as presented in Figure 33, even though the population keeps its 99.5%, the total-bio stays constant at more than 88%.

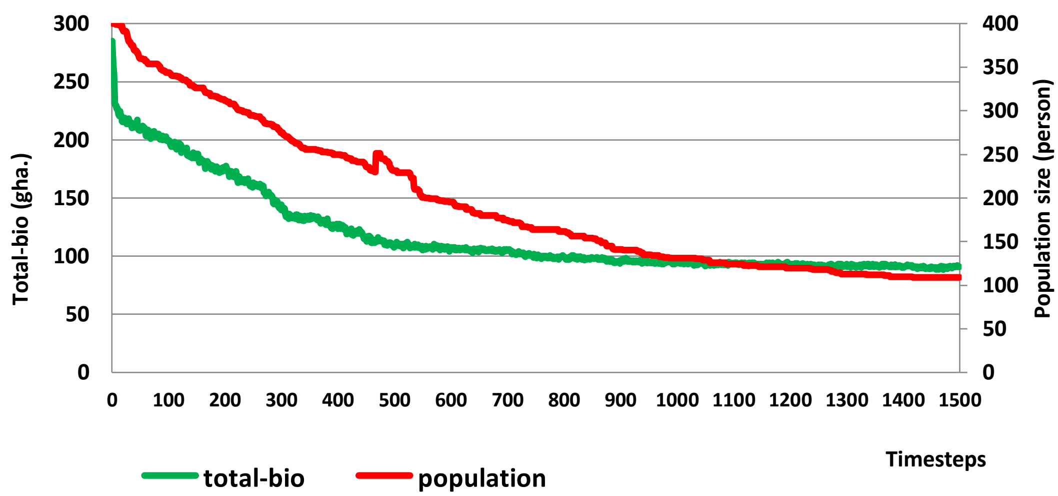

Figure 32. System structure and function: population size and total-bio under the Controlling Management (CM) system

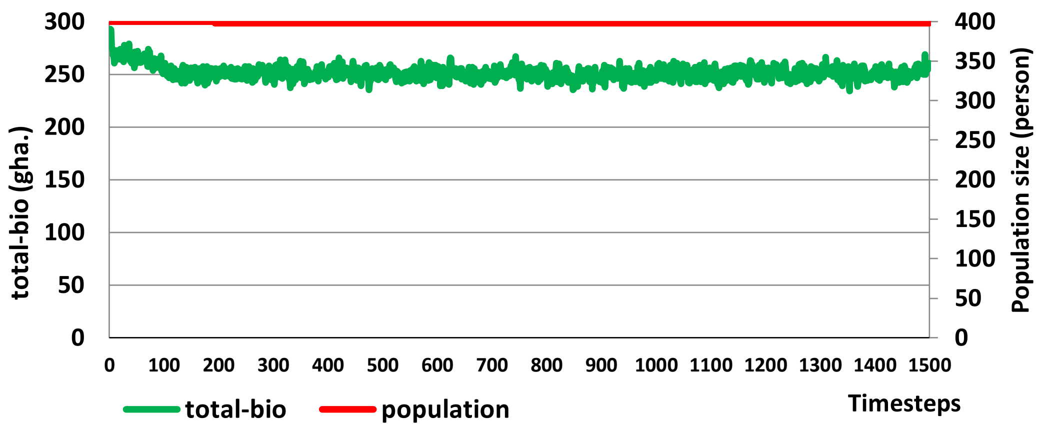

Figure 33. System structure and function: population size and total-bio under the Resilience-building (RB) system

5.2.3 Individuals' Characteristics: Resilience, Grouping, and Owning Lands

Even though individuals inherit a resilience state, their resilience scores change over time. Figure 34, Figure 35, and Figure 36 show the changes in individuals' resilience scores under three types of institutional management, considering changes in population size and the grouping state of individuals, which are two major parameters of the system. As Figure 34 shows, under No-management (NM) institutional system, after the model started, the number of individuals with the score level of equal or higher than 90 out of 100 jumps up until the timesteps reaches around 150. Then, it steadily continues at this level. While the number of individuals with a score between 0 and 21 increases for a very short period, the number of individuals with scores between 21 and 90 sharply decreases until the timesteps 100-150, and continues at this level. Along with these changes, the number of individuals with the resilience score of less than 0 emerges at 45-50 timesteps and continues to rise slowly until the timesteps 100-150, and stays quite at the same level. The pattern of increasing the number of resilient (R) individuals with a score higher than 90 follows the same pattern of the number of grouped individuals. Also, the pattern of decreasing the number of individuals with the resilience score of larger than 0 and less than 90 follows the same pattern of decreasing the number of population in the system.

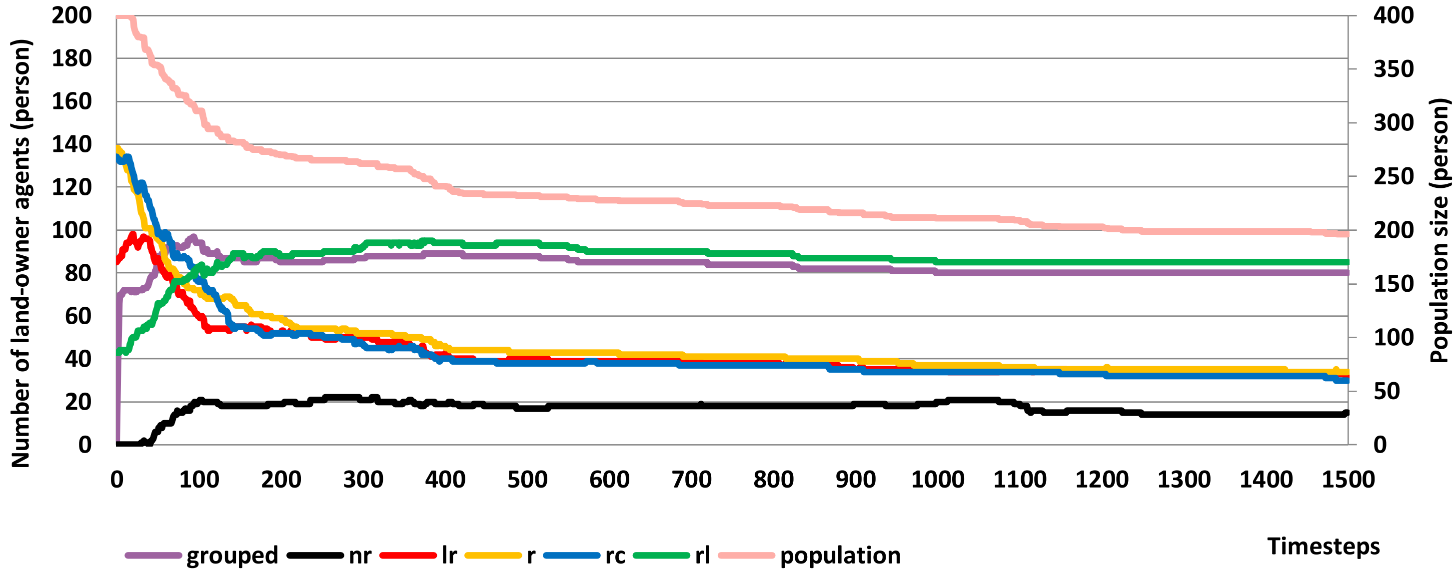

Figure 34. Population size, number of grouped land-owner agents, and resilience status of land-owner agents under the No-Management (NM) system

As Figure 35 shows, under the Controlling Management (CM) system, the population size and the number of individuals with the resilience score of larger than 0 and less than 90 sharply decreases and stays at a lower level comparing with the results under the No-management system. Under the No-management (NM) system, 49% of the population remains on their lands, while under the Controlling Management (CM) system, this rate drops to 27.25%. The number of high resilient individuals with a higher score than 90 increases more than 190% under the No-management (NM) system, while this rate is more than 130% under Controlling Management (CM). In both management systems, the number of grouped individuals at the early stage is more than the number of individuals with the highest resilience score (>= 90). This indicates that, at the early stage of the model, some of the individuals with a lower resilience score than 90 become grouped. However, after a while, the number of grouped individuals and the number of individuals with a resilience score higher than 90 is the same. This indicates that the grouped individuals are mostly individuals with a high resilience score.

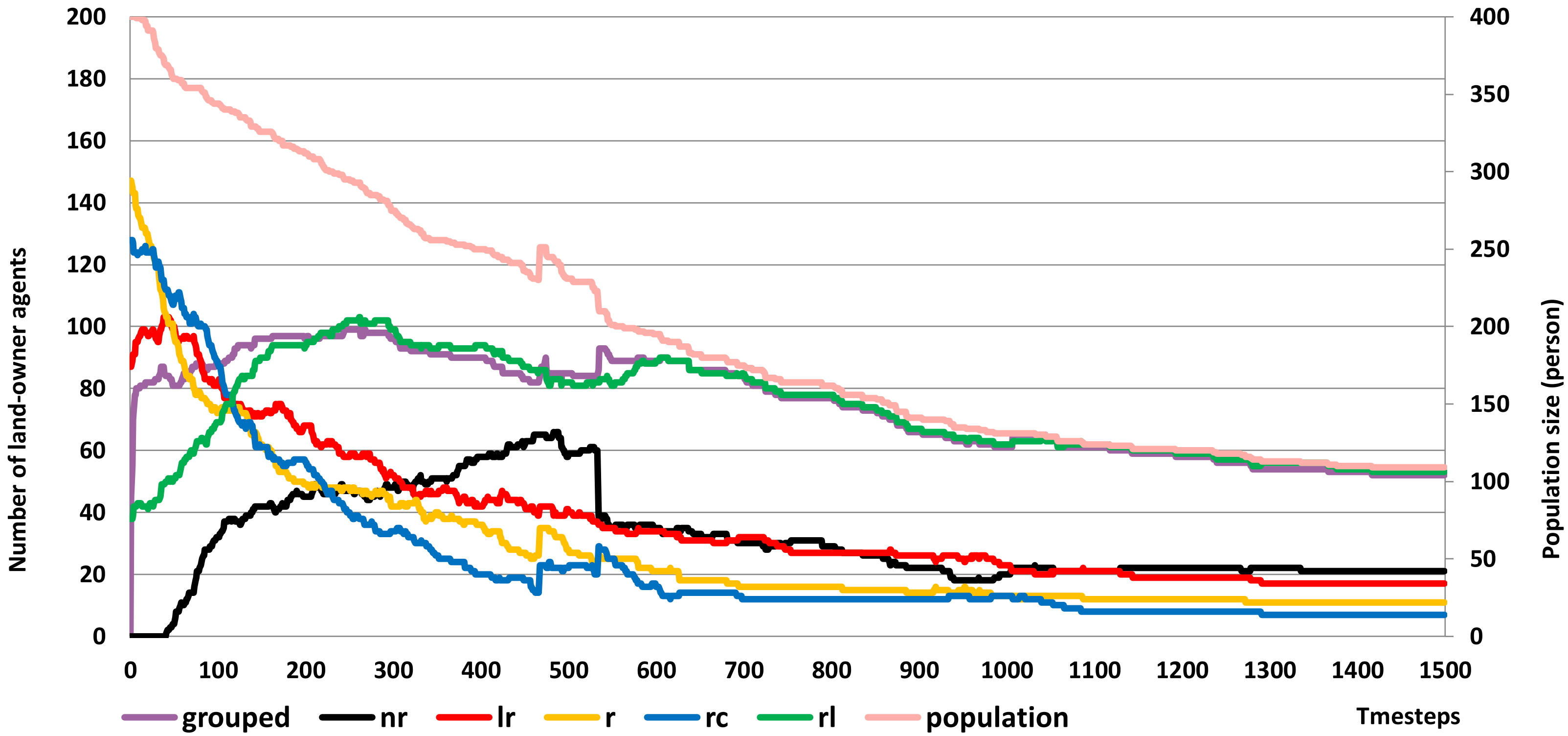

Figure 35. Population size, number of grouped land-owner agents, and resilience status of land-owner agents under the Controlling Management (CM) system

As Figure 36 shows, the pattern of resilience score of individuals and the population size under the Resilience-building management (RB) system is different from the other two management systems. In this pattern, the population size does not change noticeably and only drops 5% at the point of around 200 timesteps. The number of individuals with the highest resilience score (>=90) sharply increases. Gradually, in a different order and timesteps, the resilience score of all individuals increases to the highest number in less than 200 timesteps. First, the number of individuals with the lowest score (>=0 and <21) decreases. Then, the number of individuals with a score of higher than 21 but less than 55 declines. Finally, the number of individuals with a score of higher than 55 but less than 90 drops to 0. It is a reflection of the policy to support vulnerable individuals in this management system. Moreover, the number of grouped individuals increases until to include all the individuals but not as sharp as increasing the number of individuals with a high resilience score. It describes increasing the resiliency of individuals as the result of the policy to encourage individuals to become grouped.

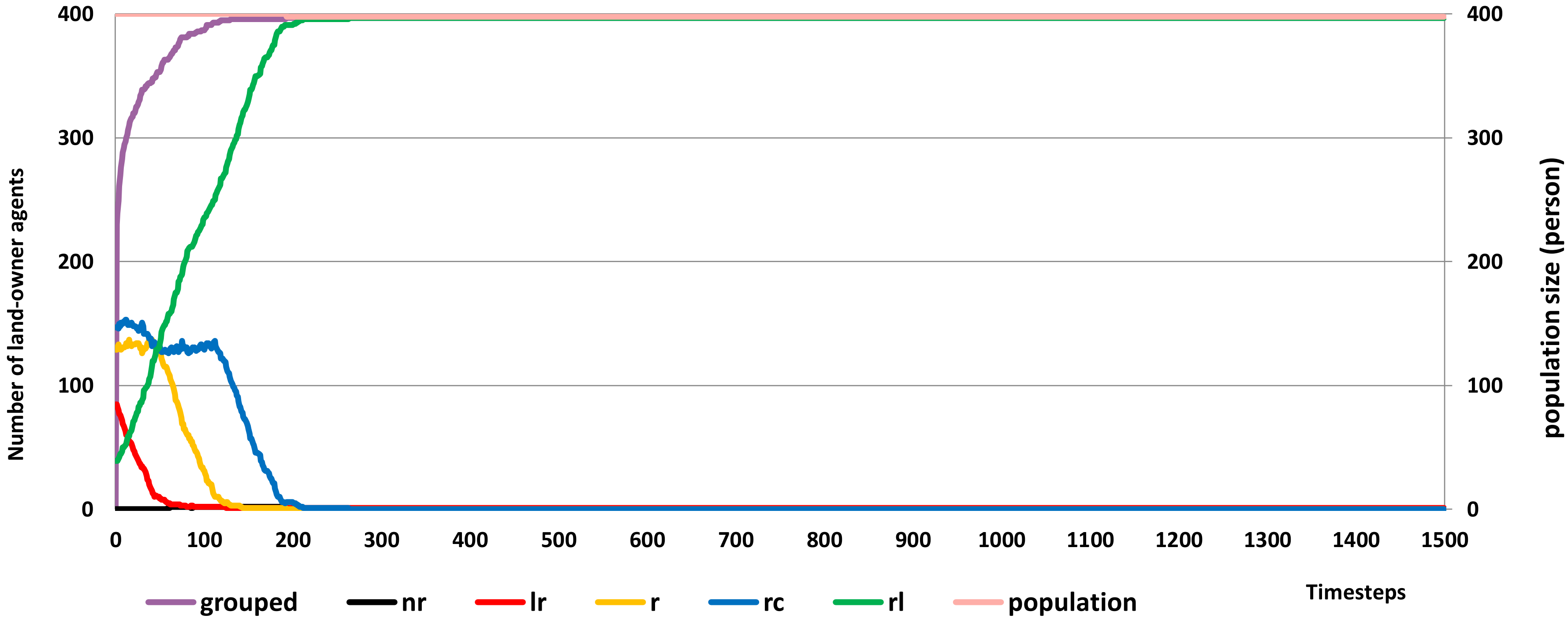

Figure 36. Population size, number of grouped land-owner agents, and resilience status of land-owner agents under the Resilience-building (RB) management system

One of the individuals' characteristics is the number of land units that they own. At the start point of the model, every individual has one land unit. When the model runs, individuals can own more land units if there is any available. They also may force to leave their lands or lose their lands due to severely affected by the disturbances or confiscated by the corrupted service-providers. Moreover, for any reason, including restoring the affected land units, individuals can own land units again. The results of running the model under three types of management systems are presented in Figure 37, Figure 38, and Figure 39.

As Figure 37 shows, under No-management (NM) system, every individual owns one land unit at the start point. While the number of individuals with land units of 2, 3, 4, and 5 increases in very early timesteps, the number of individuals owning one land unit decreases to 7.5% of the population and stays constant until the end of the model, covers around 18% of the end population. In the early stage of running the model, timesteps 2, the highest number of individuals owning two land units, and with a small difference, the number of individuals with three land units stays on top. Considering the population decreasing over time (See Figure 34), at the early stage, the number of individuals with three land units is about 39% of the early population but drops to 35% of the end population. For owning 2, 4, and 5 land units, they respectively start with 49.5%, 14.75%, and 2.75%, and end with 35%, 11%, and 0.

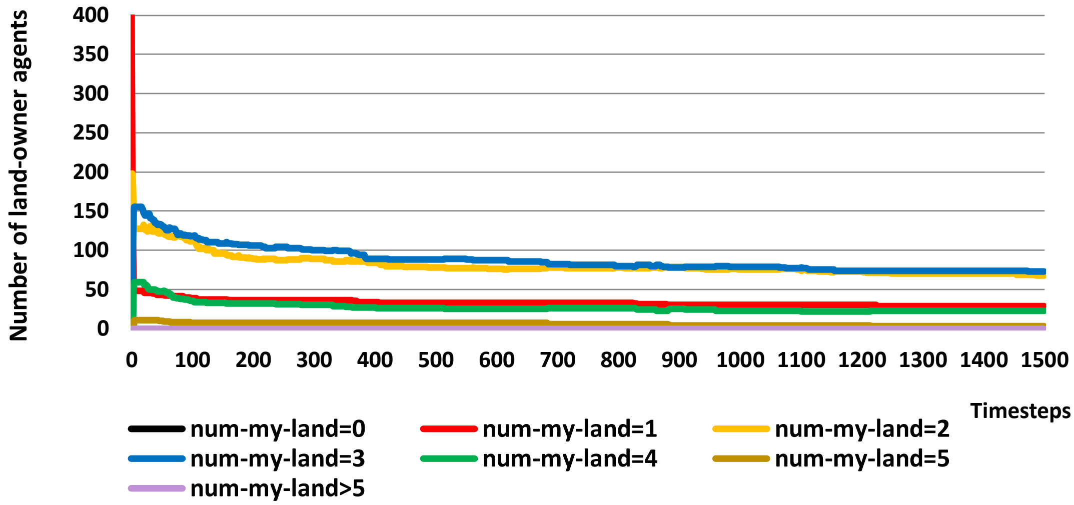

Figure 37. Owning land units under the No-Management (NM) system

As Figure 38 shows, under the Controlling Management (CM) system, the number of individuals with one land unit drops from 400 to 60 at a very early stage. The number of individuals with 2 and 3 land units is the highest number until 460 timesteps, when the owners with one land unit increase to 12 while the number of individuals owning 2 land units drops from 99 to 72. After this point, the number of individuals with all types of owning land units drops. Considering the decreasing trend in population, individuals with 3 land units are the highest number at the end of the model, consisting of 16% of the end population, while the others stay at the lower percentage around 12% to 14%.

Comparing the trend of changing owning land units under two management systems indicates that surviving requires more than one land unit and owning 3 land units provides a higher surviving option.

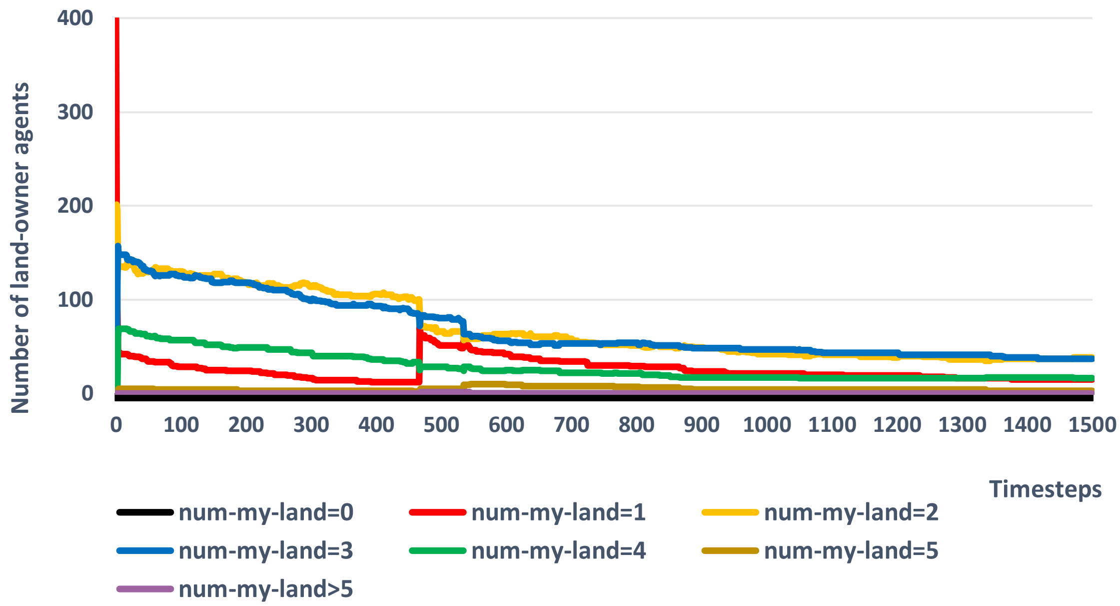

Figure 38. Owning land units by land-owner agents under the Controlling Management (CM) system

Under the Resilience-building management (RB), as shown in Figure 39,the number of individuals, who own the number of land units at the early timesteps, stay constant. They keep their lands and do not lose ownership over time. Considering a small change in population over time, individuals who own three land units with more than 36% are the highest percentage of the end population. 29% of the population own two land units, 18% own four land units, 14% own one land unit, and more than 2% own five land units.

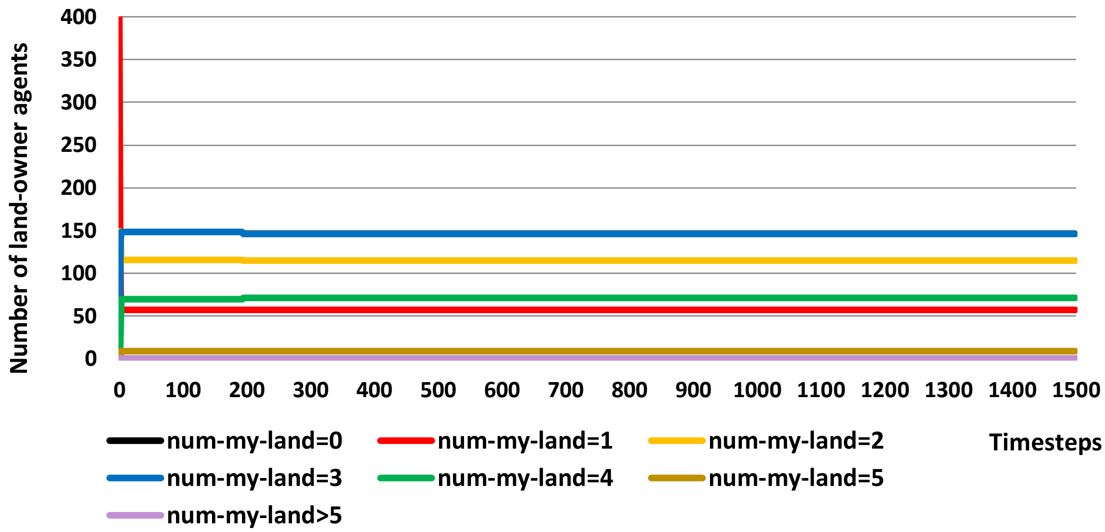

Figure 39. Owning land units by land-owner agents under the Resilience-building (RB) system

5.2.4 Land Status and Ecological Networking

Ecological dynamics and the changes in land status, including land-degradation-class and land use type can generate changes in the system resilience status, the individuals' resilience score, and the population size.

Each land unit has two characteristics of land-degradation-class and land use type, as explained in detail in Chapter Four. The land-degradation-class of land units change over time due to the neighboring land-degradation-class, the decision is made by the land-owner agent, and whether or not the land unit is affected by the ecological network. The land use types of the land unit can change based on the strategic decisions that are made by the land-owner agents, considering the land use requirements, including grouping with the neighbors and the possibility of doing so, and the bio-capacity of the land uses applying their experiences. Whether or not the land unit is affected by disturbances that is release through ecological networking changes over time. As the network grows the possibility of releasing disturbances changes. The constant attaching the natural-connector agent that locates on a land unit to a larger network or detaching from is one of the situations that changes the land unit that is affected by disturbances over time.

The changes in land-degradation-class under three management types are presented in Figure 40, Figure 41, and Figure 44.

As Figure 40 shows, under the No-management (NM) system, the affected land units, as dead lands, comprises 60% of total land units. They are developed over time when the disturbances release and affect potential land units. Land units with land-degradation-class (es) of 1 and 4 stay at the top, each consisting of around 16% of total land units. More than 7% of land units with land-degradation-class 4, are ready to link the ecological network. Land units with land-degradation-class (es) of 3 and 2 respectively comprise 7% and 3% of total land units.

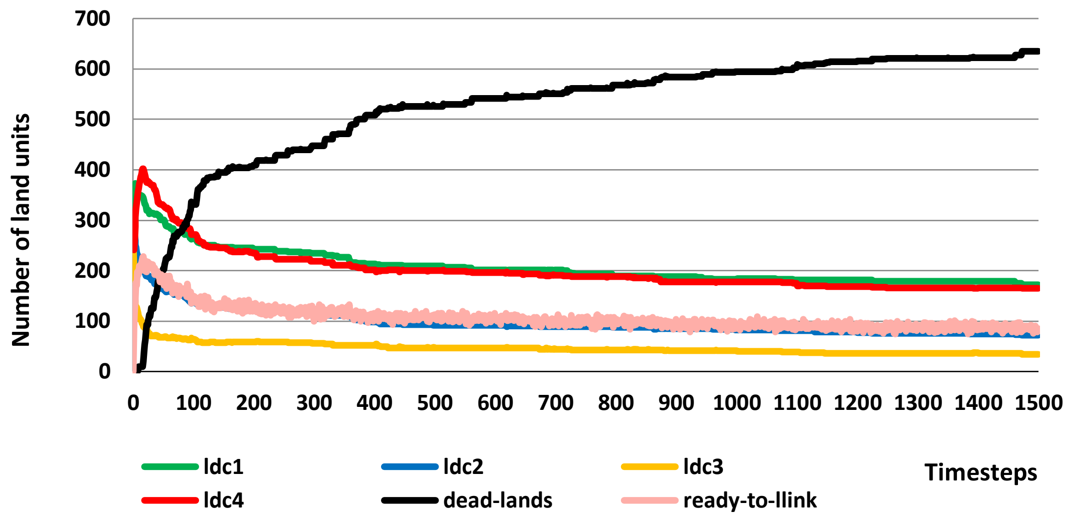

Figure 40. Land status: land-degradation-class of land units under the No-management (NM) system

Under Controlling Management (CM), as shown in Figure 41, land units with land-degradation-class 4 take over the land units with land-degradation-class 1 at the early timesteps, point 8. They start covering 23.6% of the land units but end with 60.7%. Even though dead lands rise to their highest number at timesteps of 50, covering around 12% of total land units, present a constant fluctuation over time, and final timesteps just cover 6% of total land units. It reflects the management policy and the efforts by service-providers to address and improve the dead lands. Moreover, out of total land units with land-degradation-class 4, which covers 60% of land units, 22% are ready to join the ecological network, which potentially could release disturbances and convert land units to dead lands. This explains the fluctuation of dead lands. Still, land units with land-degradation-class (es) of 1, 2, and 3, cover 22%, 15.5%, and 2.5% of the total land units, respectively.

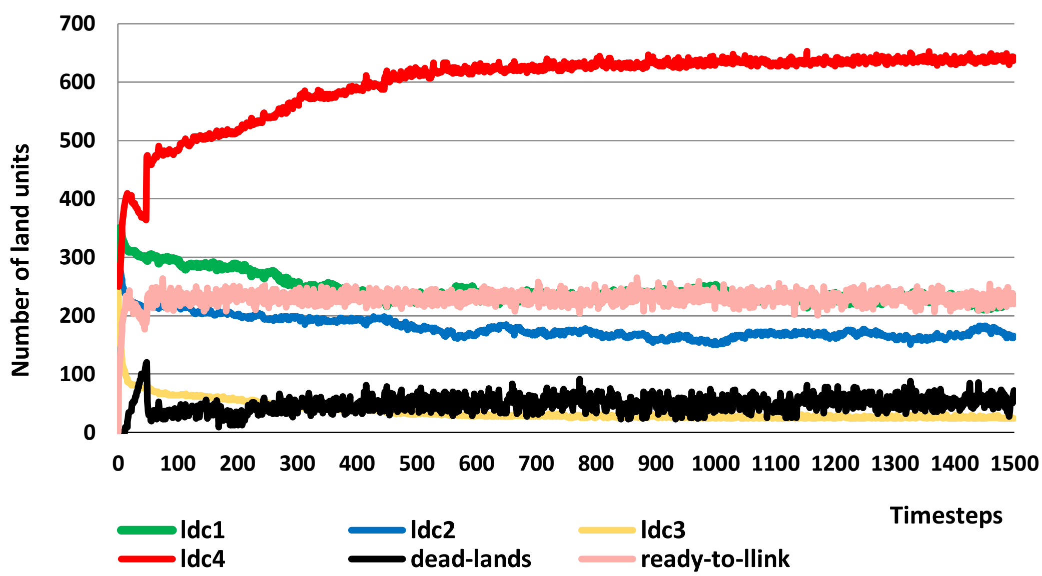

Figure 41. Land status: land-degradation-class of land units under the Controlling Management (CM) system

Under the Resilience-building management (RB) system, as Figure 42 shows, no dead land unit emerges and no land unit with land-degradation-class 4 remains. Moreover, the land units with land-degradation-class (es) 1 and 2 stay at the highest level with 50% and 41%, respectively. In comparison with the starting point, the number of land units with land-degradation-class 3 decreases and at the end it covers 10% of total land units. The number of land units with land-degradation-class 4 that are ready to join the ecological network, covers 2.7% of total land units. This indicates that still, land units with land-degradation-class 4 are emerging. However, because these land units are addressed by the service-providers they disappeared as the land-degradation-class 4 but their impacts remain.

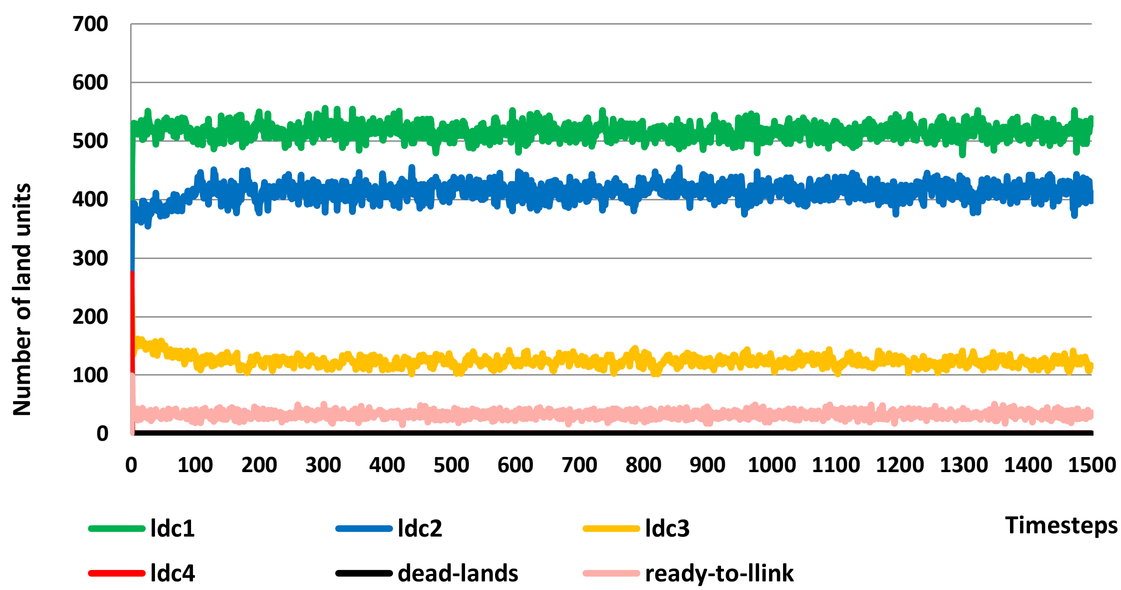

Figure 42. Land status: land-degradation-class of land units under the Resilience-building (RB) system

The changes in land use types under three types of management over 1500 timesteps are presented in Figure 43, Figure 44, and Figure 46.

Under No-management (NM) system, as shown in Figure 43, land-owners decide based on their experiences and considering the lands' characteristics. At the system level, this individual-based strategic decision leads to decreasing the number of croplands at the early stage. While in the first 5 timesteps the cropland units decrease from 77% to 45%, the other four types of land use cover 55% with the order of fishing grounds, grazing, built-up, and forest. This pattern steadily continues over the model's timesteps.

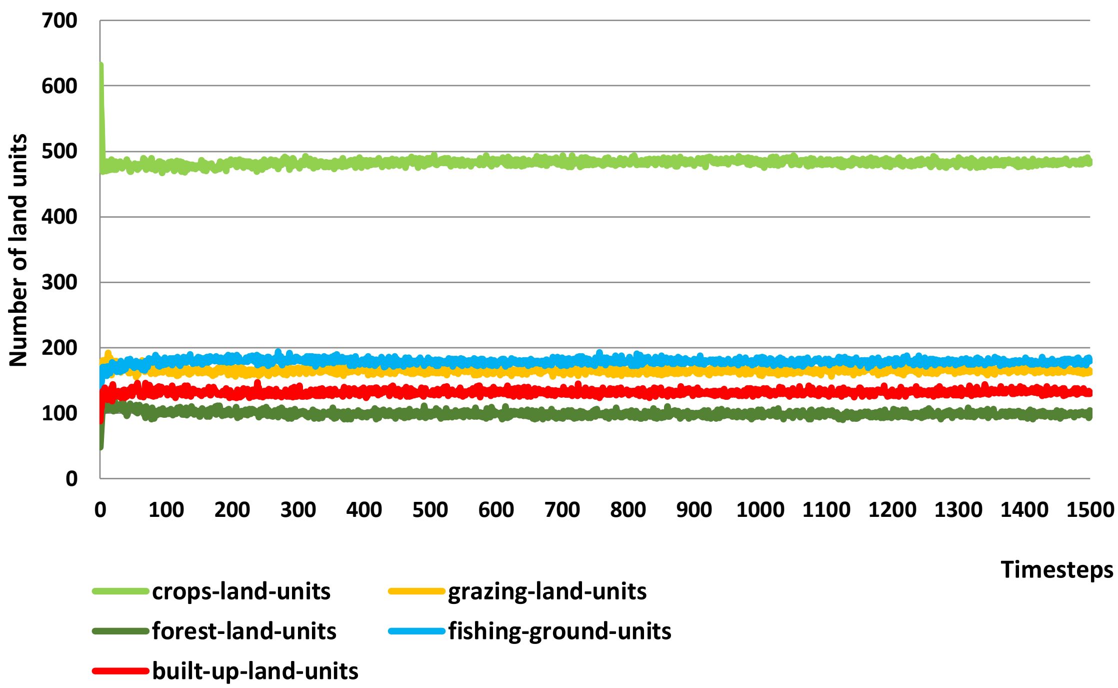

Figure 43. Land status: land use type of land units under the No-management (NM) system)

Under the Controlling Management (CM) system, as shown in Figure 44, at the early stage of the model, the number of cropland units drastically drops from 60.3% and ends with coving 12.12.6% of total land units, while the number of built-up land units increases from 9.6% to 74.8%. Figure 48 may explain this difference. As seen in this Figure, the number of land-owner agents who decide for built-up land use is as low as the number of land-owner agents of the other types of land uses. Therefore, there should be someone else who decides to change the land use of the land units to the built- up. They could be corrupted service-providers, who confiscate some of the land units under specific conditions, as explained in Chapter Four. Under the Controlling Management (CM) system, there is more likely that the supported corrupted service providers by their peers and higher managers change the confiscated land units to the built-up lands. Even though there are some opportunities that corrupted service-providers may be caught by the not corrupted service-providers and be sent to the managers of the service-providing centers and probability of being punished, the results show that under Controlling Management (CM) system the number of corrupted service-providers increases over time and finally all of the service-providers are corrupted, which increases the possibility of confiscating land units for themselves, as shown in Figure 45.

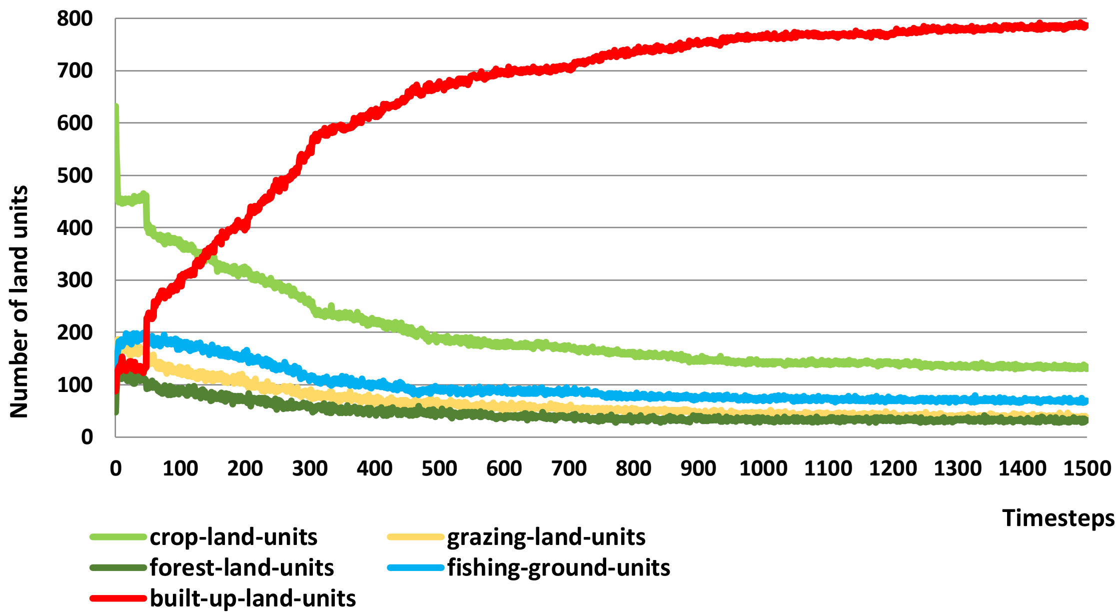

Figure 44. Land status: land use type of land units under the Controlling Management (CM) system

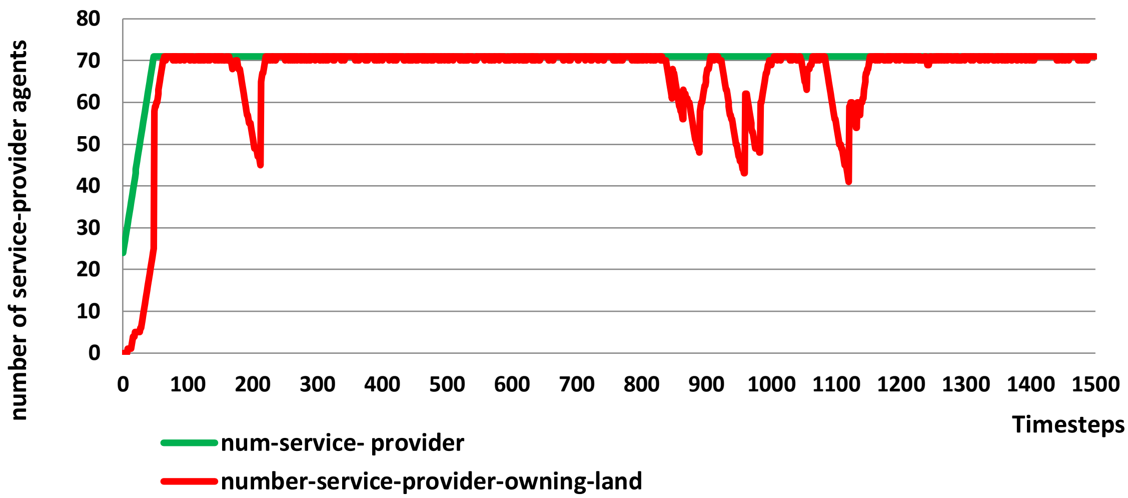

Figure 45. Number of service-provider agents and corrupted service-provider agents who own land units, under the Controlling Management (CM) system

Under the Resilience-building management (RB) system, as shown in Figure 46 all land use types shift to the middle and smoothly continue with the least fluctuation. The cropland units at the early stage drop from 60% to 31% and end with 26%. The built-up land units at the early stage cover 8.3% and end with 15.7%. Fishing land units stay around 17-18%, forest land units move from 4.5% to 15.7%, and grazing land units continue at 19-20% of total land units.

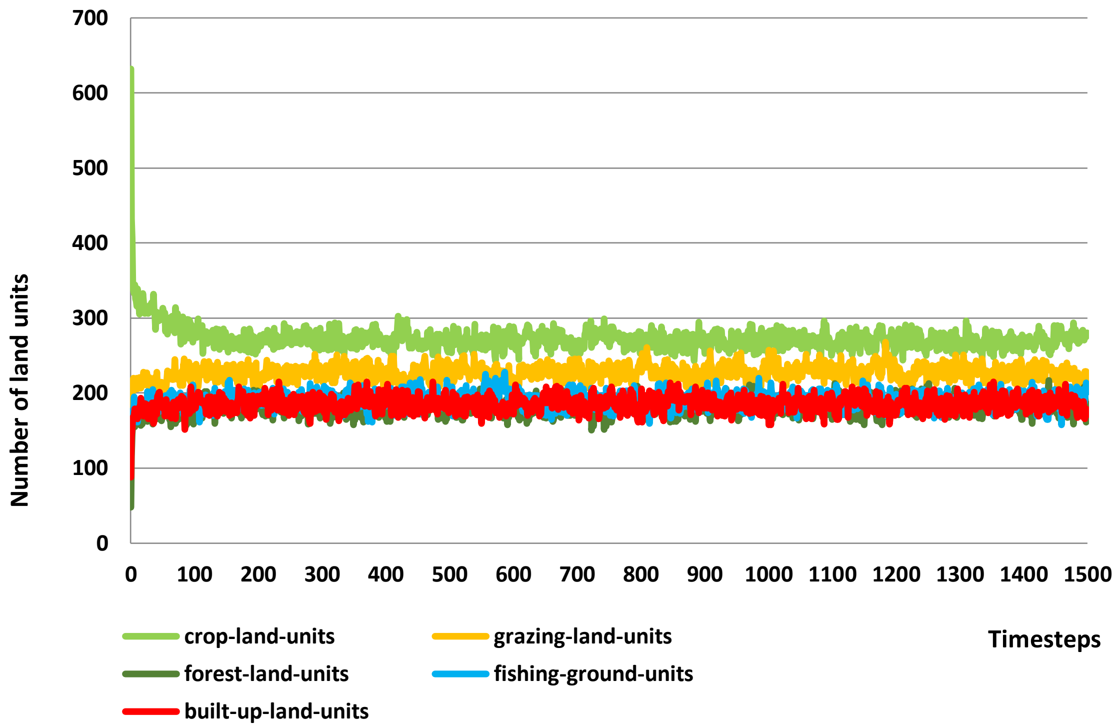

Figure 46. Land status: land use type under the Resilience-building (RB) system

Individuals as land-owner agents are the decision-makers for the land use type of their lands. However, under specific conditions, if any land unit is confiscated by service-provider agents, instead of the land-owner agents, the service-providers decide for the type of land use of the confiscated land units Figure 47, Figure 48, and Figure 49 present the changes of land use types based on the land-owner agents' decisions. Comparing

Figure 48 with Figure 44 reveals that the main decision-makers for high built-up land use under the Controlling Management (CM) system are not land-owner agents. Additionally, Figure 47 and Figure 49 show that the land use decision-makers under the No-management (NM) and Resilience-building management (RB) systems are land-owner agents.

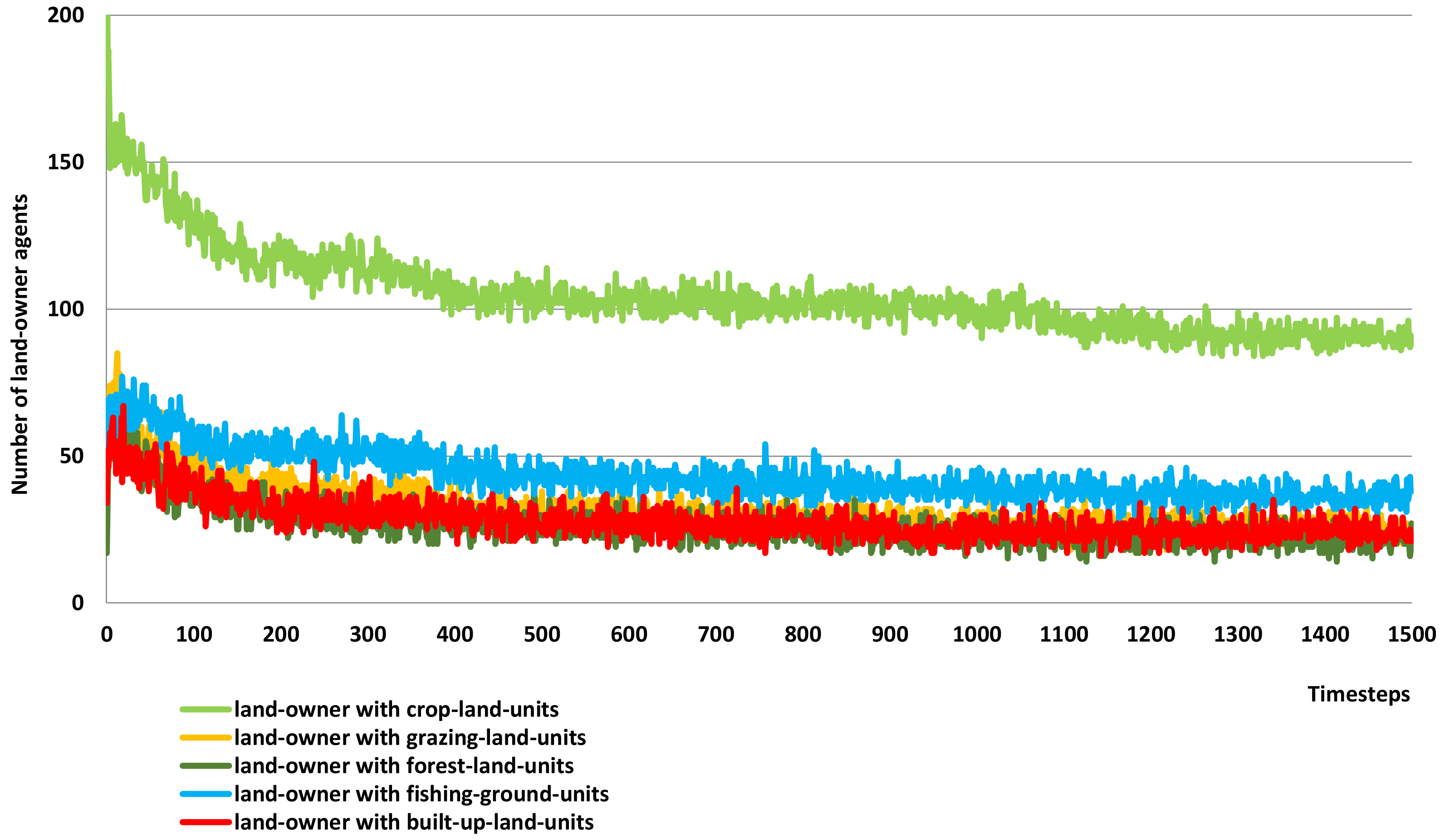

Figure 47. Land status: land use type, decisions made by land-owner agent under the No-Management (NM) system

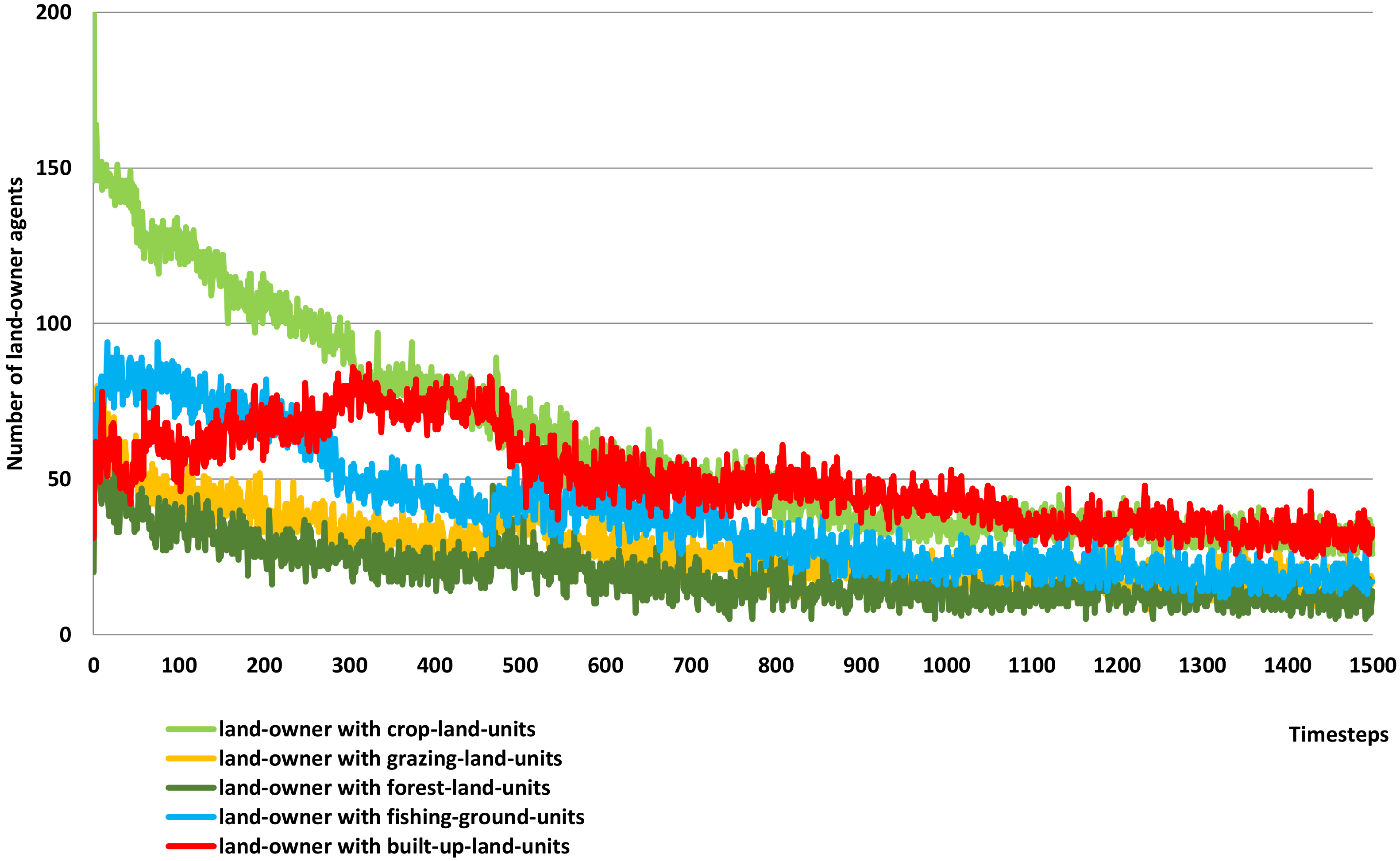

Figure 48. Land status: land use type, decisions made by land-owner agents under the Controlling Management (CM) system

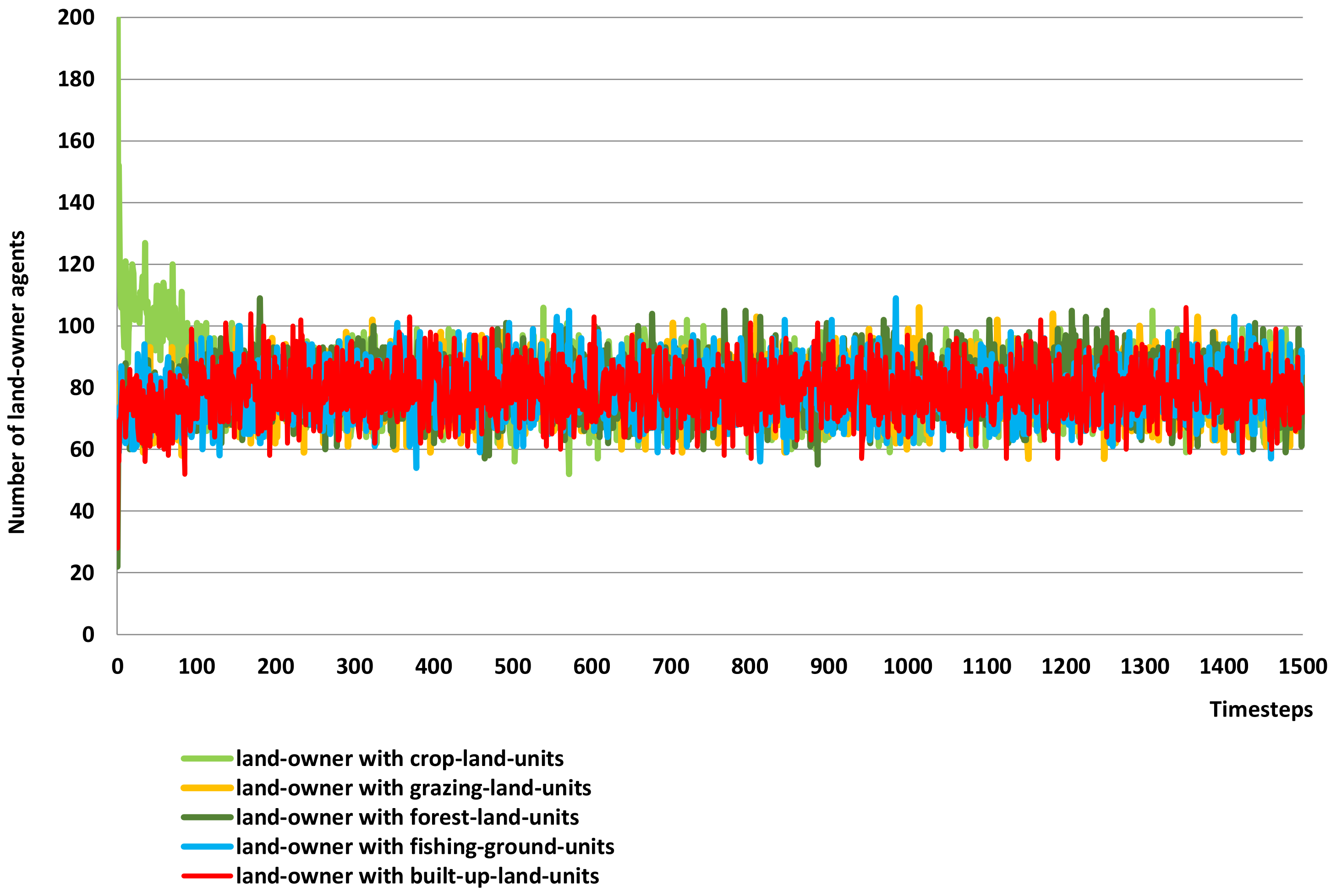

Figure 49. Land status: land use type, decisions made by land-owner agents under the Resilience-building (RB) system

Land status and land-degradation-class also can be affected by the ecological network, through which the highly-degraded land units connect, and under two conditions, as shown in Figure 9, the disturbances can release and affect the connected lands. The maximum number of links of the network, the number of links of the natural-connector agents in the network, and the identified relationships between these two parameters and two ecological thresholds are the key elements to release disturbances and change the land status. Besides the ecological dynamics, the type of management system can affect these elements. Figure 50, Figure 51, and Figure 52 present the maximum number of links and the number of the links of natural-connector agents in the network that release disturbances under three types of management.

As Figure 50 shows, under the No-management (NM) system, the ecological network reaches its highest number of links in the early stage and stays constant until the end of the model. It is the same for the links of natural-connector agents to release their disturbances. Therefore, the network reacts naturally to the ecological actions and interactions. Comparing this with Figure 51, which presents the result of ecological networking and releasing disturbances, indicates that the Controlling Management (CM) system interrupts the ecological process and makes some delays to the ecological network to reach its highest number of links as well as natural-connector agents in the network to release the disturbances. Figure 52 shows that under the Resilience-building management

(RB), no ecological network can be formed due to the policy that taking care of lands and land-owner agents.

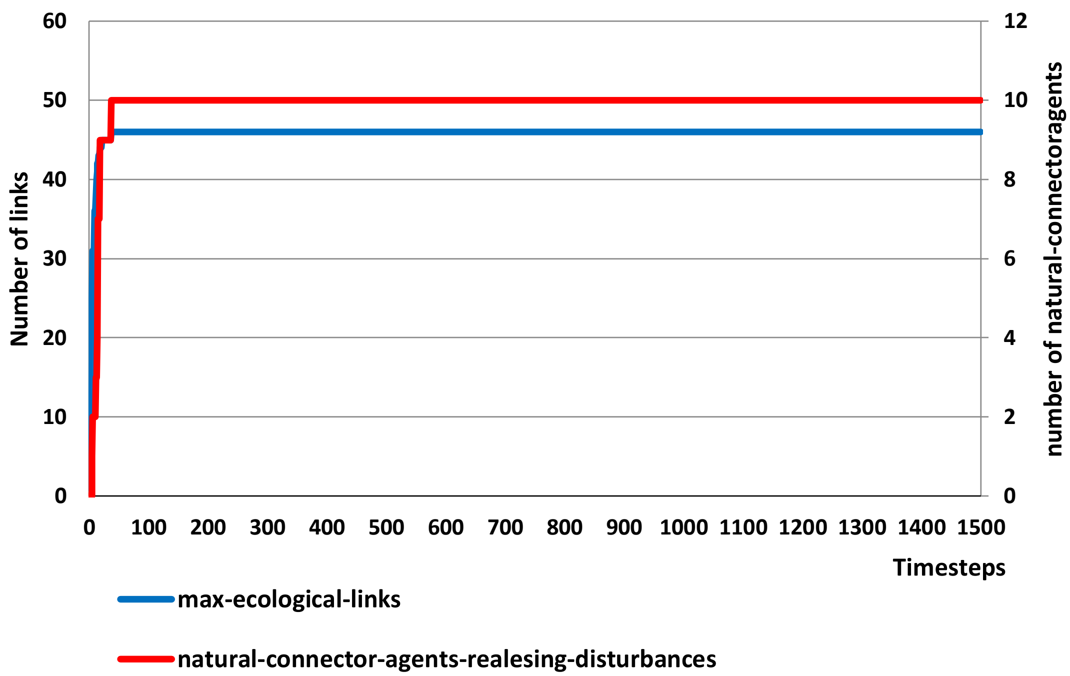

Figure 50. Ecological network: releasing disturbances under the No-management (NM) system

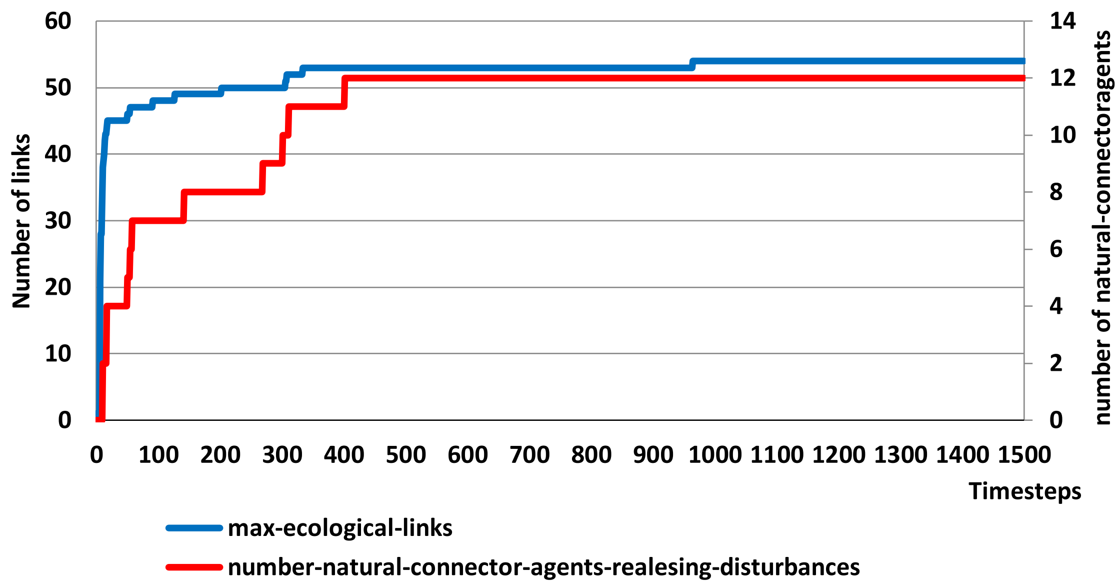

Figure 51. Ecological network: releasing disturbances under the Controlling Management (CM) system

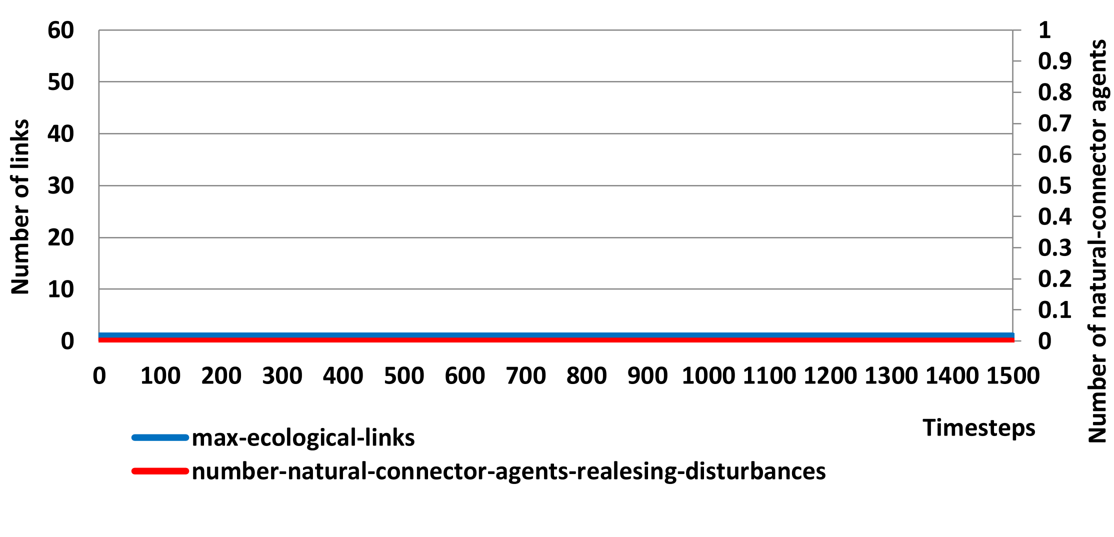

Figure 52. Ecological network: releasing disturbances under the Resilience-building (RB) system

5.3 Verification, Validation, and Sensitivity Analysis

For verification at the individual level, the baseline model with No-management (NM) institutional management is used. The objective of verification is to ensure that the main parts of the model with the basic variables, especially the ecological attributes, land-owner decision-making variables, and sub-models function as they are supposed to. The basic method of verification is applied to the model with two other management systems of Controlling Management (CM) and Resilience-building (RB) to identify any management bug. Moreover, the command part of the NetLogo is used to find changes in the numbers of agents and their attributes. The world view info part is used to randomly follow specific agents or locations to understand how their variable states change by applying the go-once command. Under varying different setups, including the thresholds for connecting land units, releasing disturbances, and increasing/decreasing service-providers, the model is operated as many times as sufficient. There are no unexpected variable states or changes in attributes. Therefore, the model does not show any programming bugs.

As an explanatory model, an internal validation as a result of sustaining outputs under different sensitivity analyses would give a satisfactory level to the model. For internal validation, different sensitivity analyses should be applied by changing the parameters. However, not all parameters can be changed in this model because they are forming the model foundation. For example, the population number, the number of land units that are allocated to different land-use types, and the biocapacity of each land-use type are basic for the model because they are proportionally representing the numbers of the country of case study, as described in Chapter Three. Moreover, some of the numbers such as thresholds for connecting and affecting neighboring land units or forming the ecological network are fixed after trying many times with different numbers to let the model function as it is supposed. For example, to let the degradation classes of land units change due to neighbors' land-degradation -classes, the complete arbitrary numbers are applied. As these connections of neighboring lands and affecting each other are forming the blocks of the model they cannot be changed for verification. If they are increased or decreased the model stop working because the land units either not connecting or connecting so rapidly that the other parts of the model do not have time to function and form the model. This is how numbers root in the model itself.

Still, the main parameters that could affect the result of the model are selected through observations and applied for sensitivity analysis. For the ecological subsystem, two parameters of land unit's ecological capacity to hold disturbances when they are in a network, which is called agent-in-network-ecological-threshold, and the network-ecological threshold are varied to find out how they affect the model and whether the results are reliable under the selected thresholds. These two parameters play role in releasing disturbances and affect decisions by individual land-owner agents as well as the management system. Two other parameters that may affect individual land-owner agent's decisions are the memory-size of individuals, which reflects the number of times that they can remember their experiences and the number-of-strategies that they have available. The other variables such as corruption capacity of the management system or knowledge required for individual agent's strategy are parameters that not only their effects are obvious but also do not directly answer the research questions. So, these parameters are excluded from sensitivity analysis.

5.3.1 Effect of Memory Size and Number of Strategies

Individual land-owner agents rely on their past experiences to choose strategy to manage their lands. Obviously, not all agents remember the past experiences the same. Some of them remember longer than the others, but, there is a maximum of times as the memory size. To understand the effect of memory size on the system resilience the memory size is altered while the number of strategy is fixed at the minimum. The comparative result of changing memory size from 3 to 10 on the base line model, in which No-management is applied, can be found in Figure 53 and Figure 54. In these experiments the agents' ecological capacity to hold disturbances, which is called agent-in-network-ecological-threshold, is set at 10, and the ecological network capacity, which is called network-ecological-threshold is set at 35.

Comparing two Figure 53 and Figure 54 indicates that increasing the memory size doesn't affect the final result after 1500 timesteps. However, it delays the system to emerge the Transferred (T) status while giving early opportunity to emerge the Not-resilient (NR) state of the system. Also, it gives less opportunity to Low-resilient (LR) state to move to the highest state of the system as it presents in the situation with less memory size.

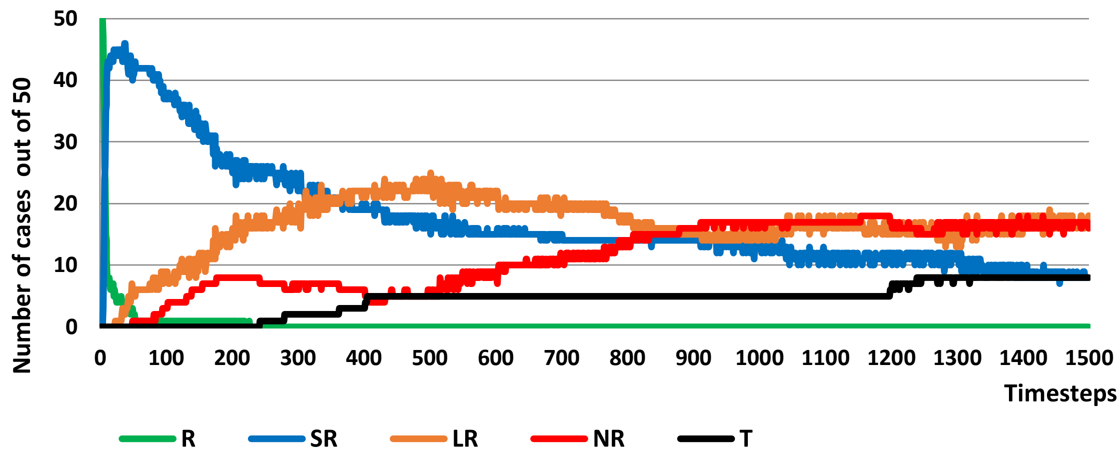

Figure 53. System resilience status under the No-management (NM) system (memory-size: 3, number-of-strategies: 5)

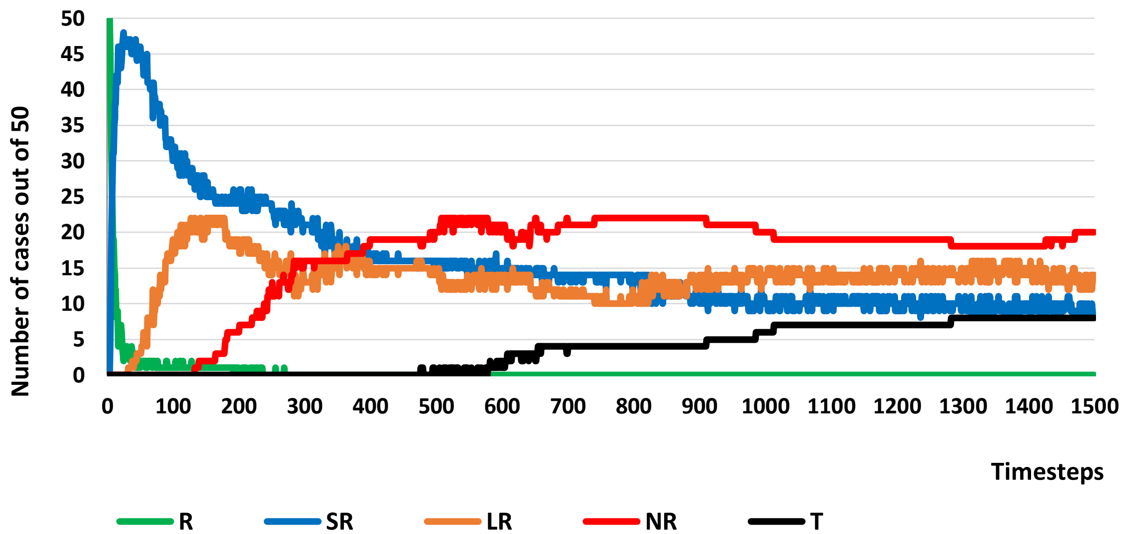

Figure 54. System resilience status under the No-management (NM) system (memory-size: 10, number-of-strategies: 5)

To understand whether the number of strategies that are available to land owner agents affects the system resilience status, another experiment is applied by increasing the number-of-strategies to the highest of 10 while the memory size stays at the low level of 3. The result is presented in Figure 55. Comparing two Figure 54 and Figure 55 indicates that increasing the number of strategies keeps the system state of Transferred (T) very low while the state of Not-resilient (NR) stays a little bit higher. To learn whether the highest memory size and number-of-strategies affect the system resilience status, another experiment with memory size of 10 and number-of-strategies of 10 is applied and the result is given in Figure 56. Comparing two Figure 53 and Figure 56, while the memory size and number-of-strategies are in the lowest and highest respectively, indicates when both parameters are in their highest, the state of Semi-resilience (SR) status of the system drops earlier, the Not-resilient (NR) state is developed to its highest level earlier, and the Transferred (T) state of the system reaches to its highest later than when both parameters are in their lowest numbers.

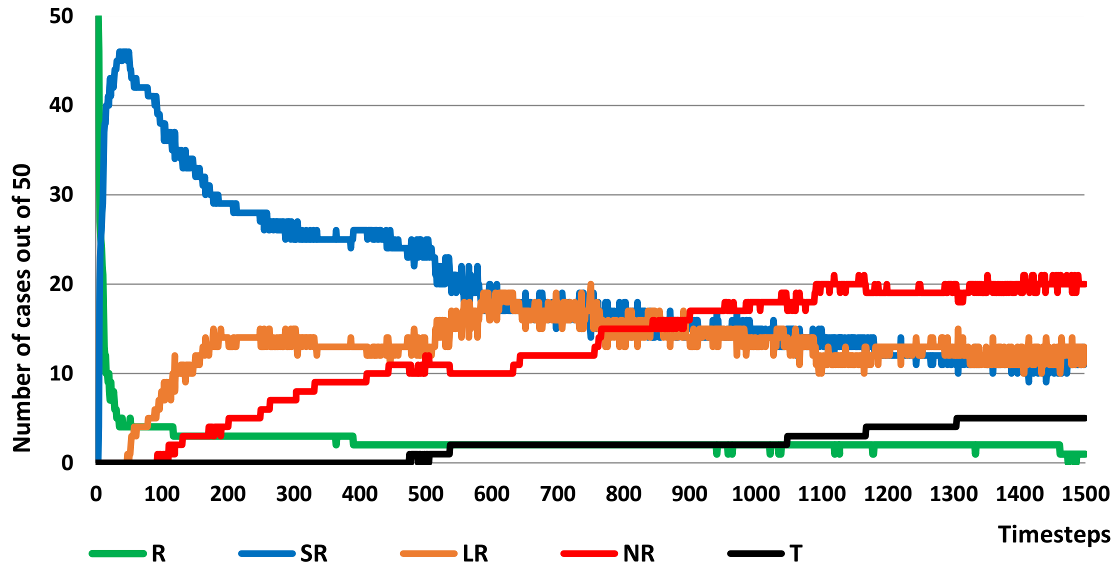

Figure 55. System resilience status under the No-management system (memory-size: 3, number-of-strategies: 10)

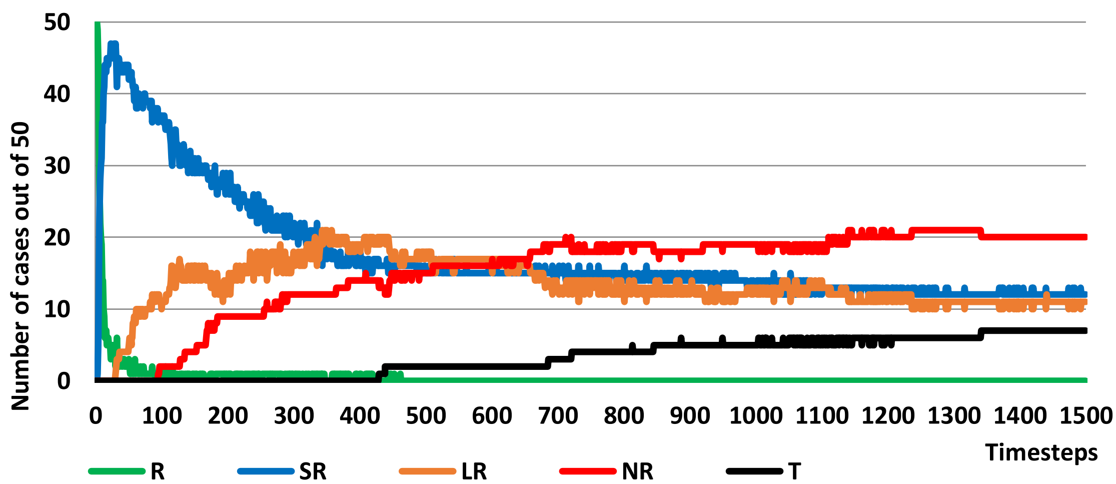

Figure 56. System resilience status under the No-management (system) (memory-size: 10, number-of-strategies: 10)

Generally, the end result of varying memory-size and number-of-strategies are very close to each other and increasing memory-size increases the state of Transferred (T) status of the system. This, concludes that the system resilience status is not very sensitive to memory- size and number-of -strategies. Therefore, the option of setting memory size to 3 and number-of-strategies to 5 looks logic while it helps the model runs faster.

5.3.2 Effect of Ecological Resilience Capacity Thresholds

As explained in Section 4.1.2 about the model's entities and variables, each natural-connector agent randomly assigned to ecological resilience capacity of holding disturbances, which is called my-ecological-resilience. This capacity is applied when natural connector agents join the ecological network. Releasing disturbances through network depends on natural-connector agents' capacities as well as the system's network capacity to hold disturbances, which is formulated in Equation 1 . In this equation, two variables, which are Natural Connector Ecological Threshold (NCET), and Network Resilience Threshold at the system level (NRT), can be changed by users. To understand how the output of system resilience status is affected by these two thresholds, the experiments are applied by varying their numbers.

The range of NCET is 1 to 20. To make the model network function, as observed over experiments, the thresholds less than 7 makes the model stop very soon. Therefore, the experiments are applied at three threshold numbers of 7, 10, and 20. For NRT, the range of thresholds is between 1 and 100. The observation, also, revealed that the threshold less than 10 for Network Resilience Threshold made the model so loose for running. Therefore, the experiments are applied while the threshold is set for 10, 35, 50, and 100.

The result of varying these two variables are presented in Figures from Figure 57 to Figure 67.

As Figure 57 and Figure 58 show, when both thresholds are set at low, in a very early stage, less than 35 timesteps, and with a very large differences the system-resilience status moves to Transferred (T) state and continues at that level. Logically, it is obvious that when the capacity of natural-connector agents individually as well as the network collectively are low to hold the disturbances, the system loses its resilience status. In terms of equation, it is also obvious that lowering natural-connector agents' capacity, ERNC, increases the result of the equation at the left side and lowering NRT, decreases the result of the right side of the equation, Therefore, the disturbances release early and massively.

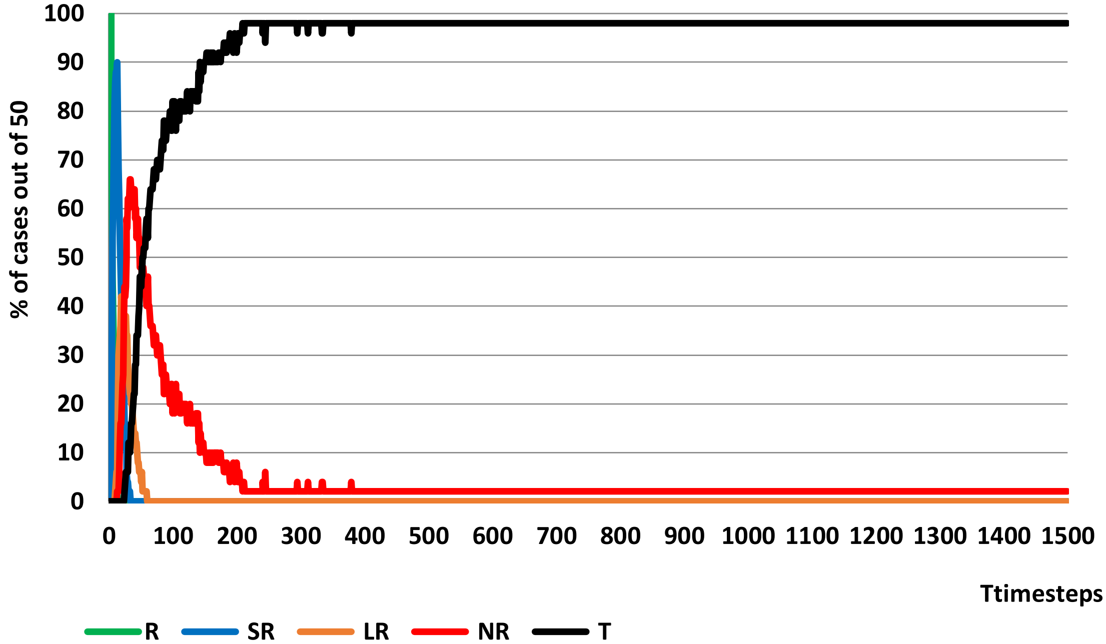

Figure 57. System resilience status under the No-management (NM) system (NCET: 7, NRT: 10)

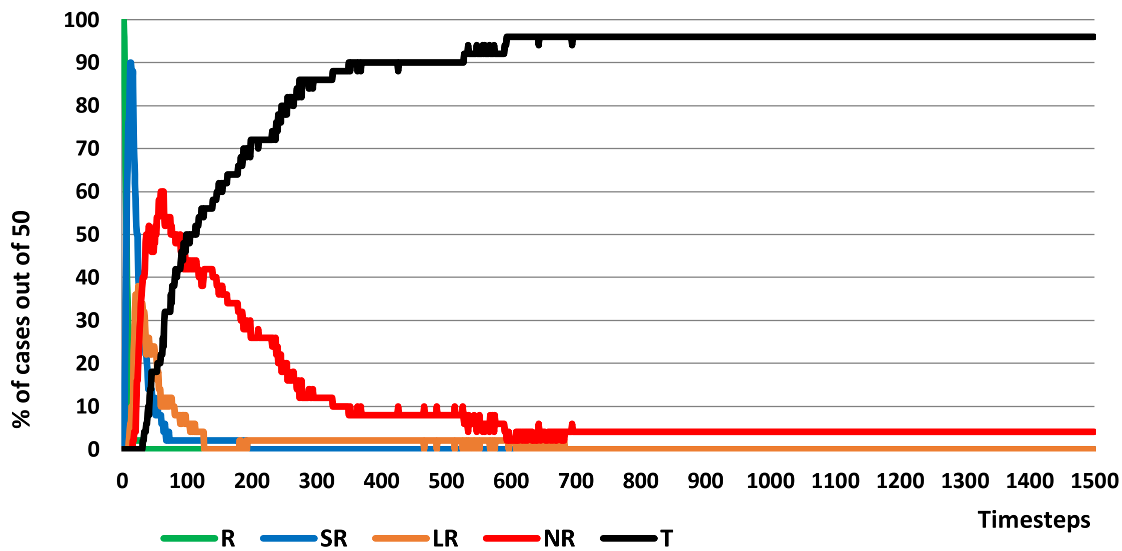

Figure 58. System resilience status under the No-management (NM) system (NCET: 10, NRT: 10)

Moreover, when NCET and NRT thresholds are set at the highest level of 20 and 100 respectively, as shown in Figure 59, both natural-connector agents individually and the network collectively are capable of holding disturbances. Therefore, the Resilient (R) and Semi-resilient (SR) are two states of the system that emerge at a very early stage of the model and steadily continues without presenting any other types of the system resilience status. When the capacity of holding disturbances by the network, NRT, decreases to 50 but the capacity of NCET stays at the highest level of 20, the result does not change, as shown in Figure 60. In the latter case, only the state of Resilient (R) decreases by 20% in comparison with the previous experiment. Decreasing NRT to less than 50 makes the system less resilient and forces natural-connector agents to release disturbances despite their high ecological capacity to hold disturbances, as shown in Figure 61 and Figure 62. This shows that natural-connector agents, individually, are vulnerable to the system network function when they have high potential of holding disturbances but cannot tolerate as much as it is expected as individuals.

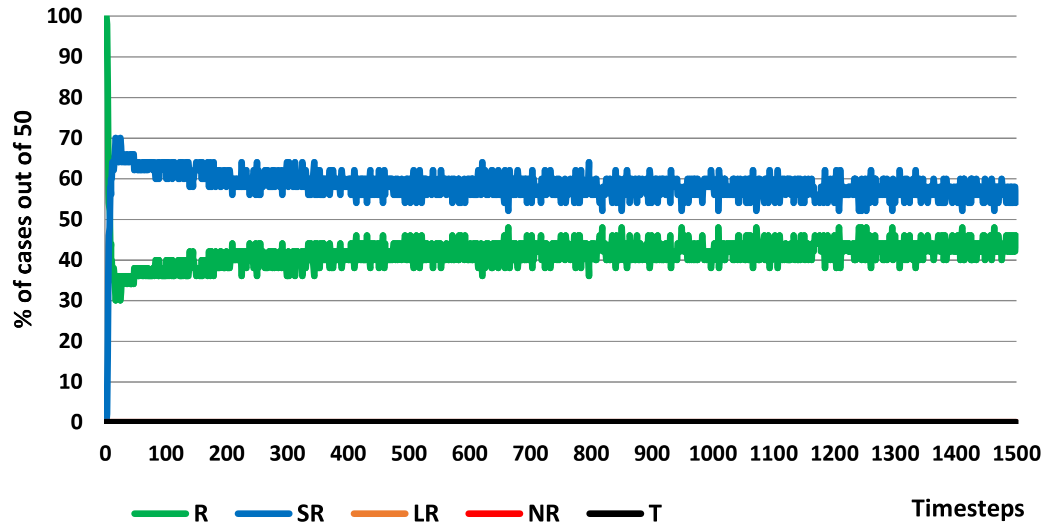

Figure 59. System resilience status under the No-management (NM) system (NCET: 20, NRT: 100)

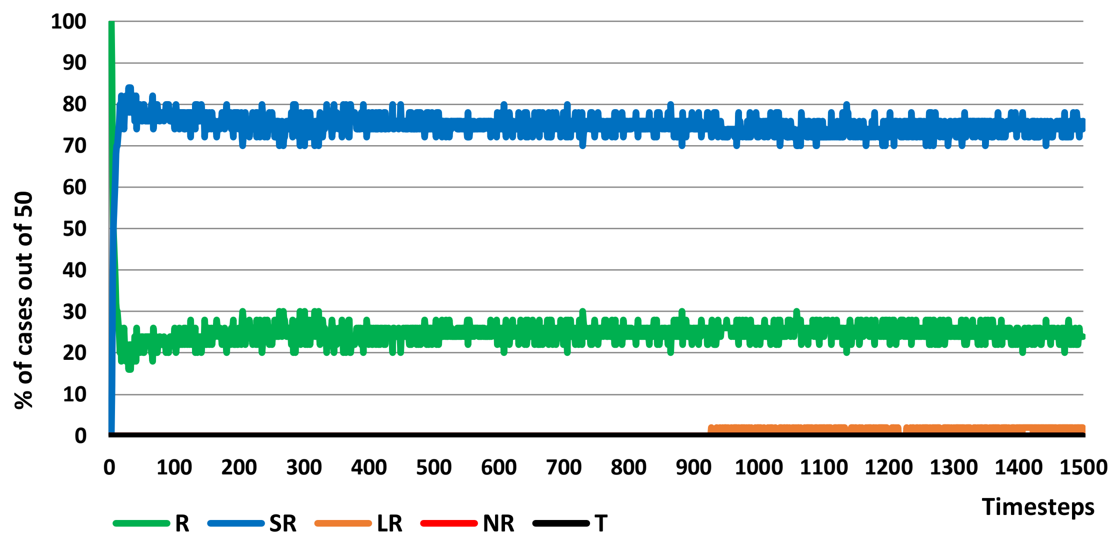

Figure 60. System resilience status under the No-management (NM) system (NCET: 20, NRT: 50)

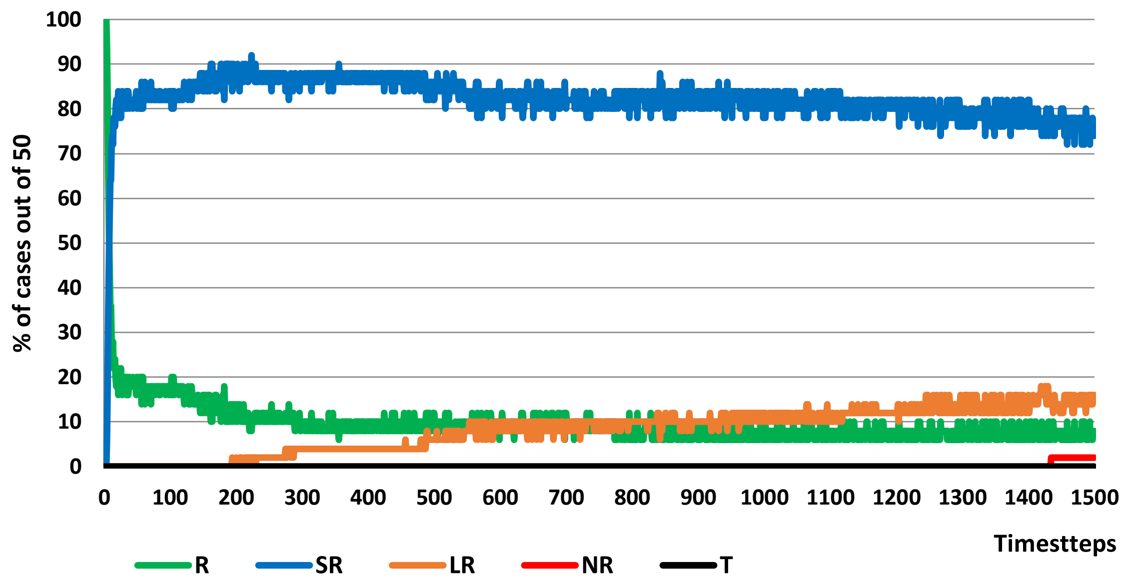

Figure 61. System resilience status under the No-management (NM) system (NCET: 20, NRT: 35)

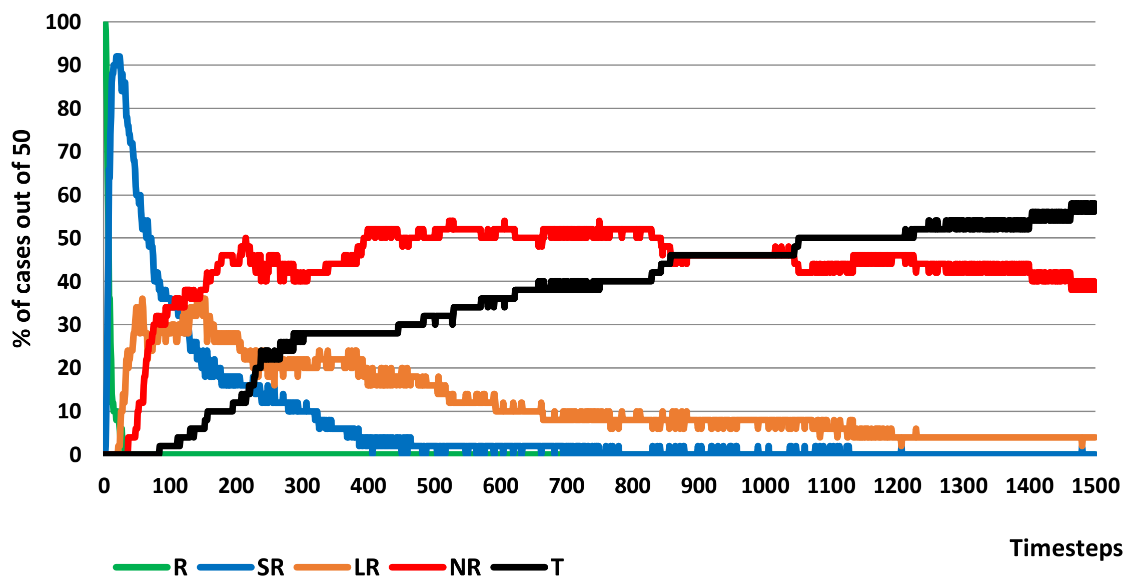

Figure 62. System resilience status under the No-management (NM) system (NCET: 20, NRT: 10)

To understand how changing NRT affect the system resilience status while NCET is set at low numbers, at 7 and 10, several experiments are carried out and the results are presented in Figure 63 to Figure 67. Comparing Figure 57, in which NCET is set at 7 and NRT is 10, with Figure 63, Figure 64, and Figure 65, in which NCET stays the same and NRT increases, indicates that increasing the capacity of the network at the system level to hold disturbances increases the system resilience status from Transferred (T) to more Semi-resilient (SR) and Resilient (R). Comparing Figure 58, in which NCET and NRT are set at10, with Figure 66 and Figure 67 shows the same trend with some differences. Comparing Figure 64 and Figure 65 with Figure 66 and Figure 67 indicate that increasing NRT to 50 and 100 when NCET is set at 10 makes the system more rigid than the model in which NCET is set at 7. In other words, the natural-connector agents with 10 capacities of holding disturbances while the network capacity increases to 50 and 100 have less opportunity to present their real capacities and the system move to unrealistic results. For this reason, setting the NCET of the final model at 7 while NRT is 50 is much closer to the real situation as presented in Chapter Three.

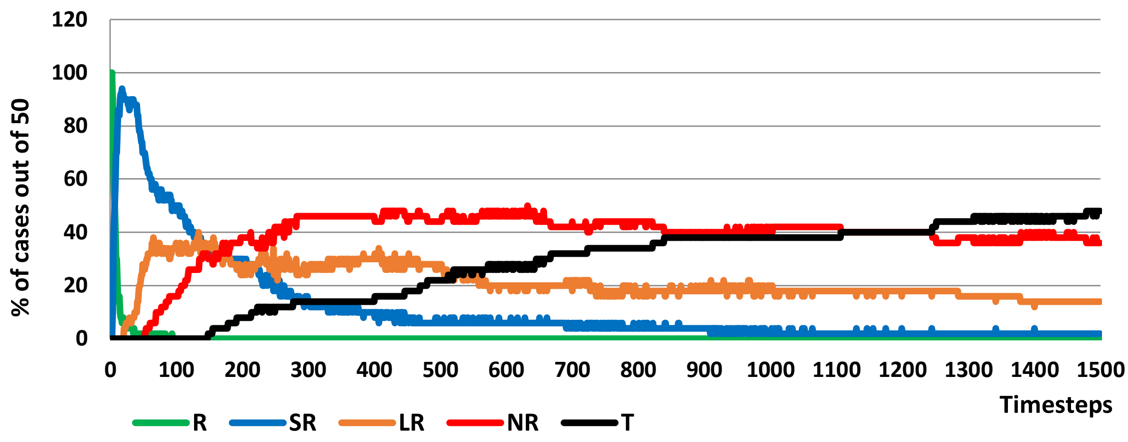

Figure 63. System resilience status under the No-management (NM) system (NCET: 7, NRT: 35)

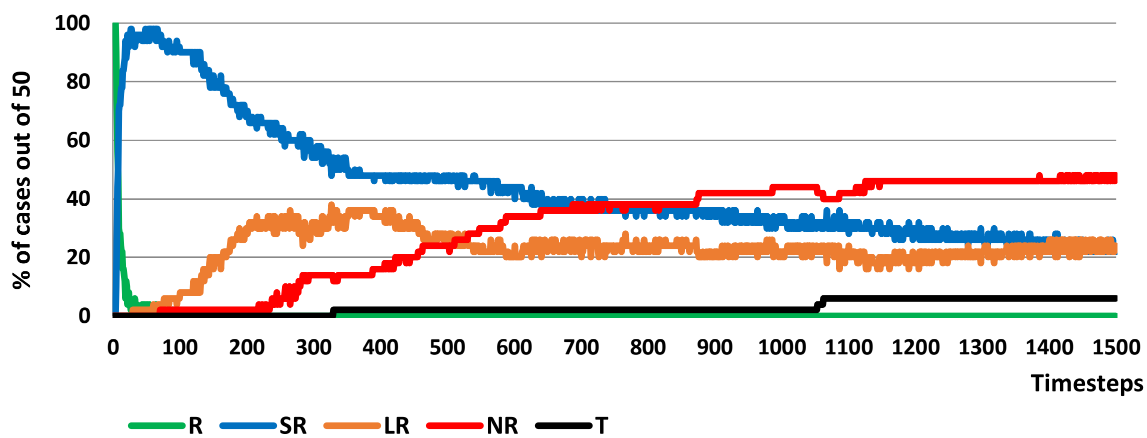

Figure 64. System resilience status under the No-management (NM) system (NCET: 7, NRT: 50)

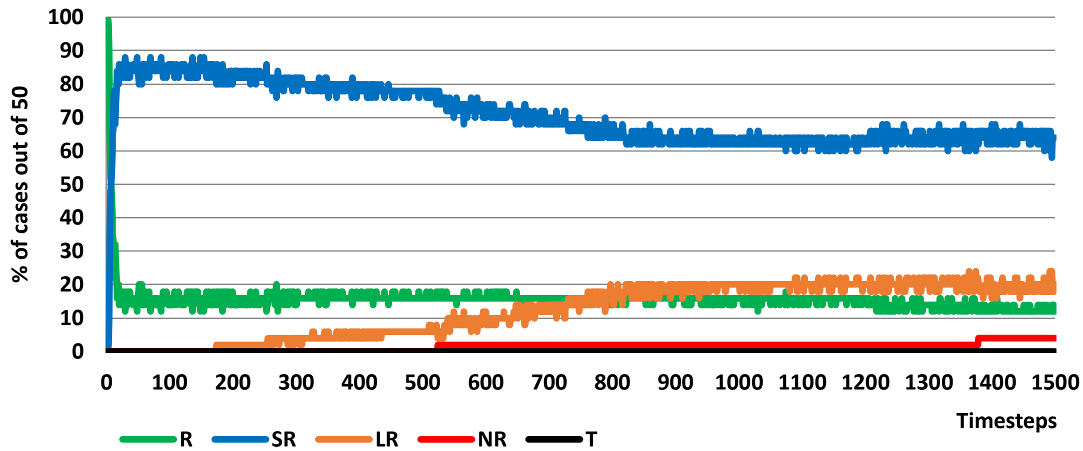

Figure 65. System resilience status under the No-management (NM) system (NCET: 7, NRT: 100)

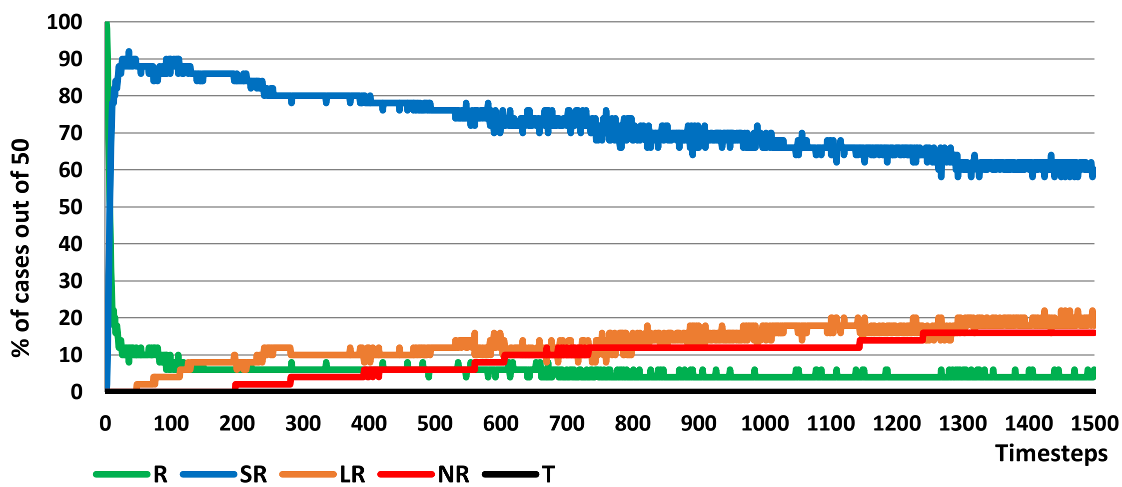

Figure 66. System resilience status under the No-management (NM) system (NCET: 10, NRT: 50)

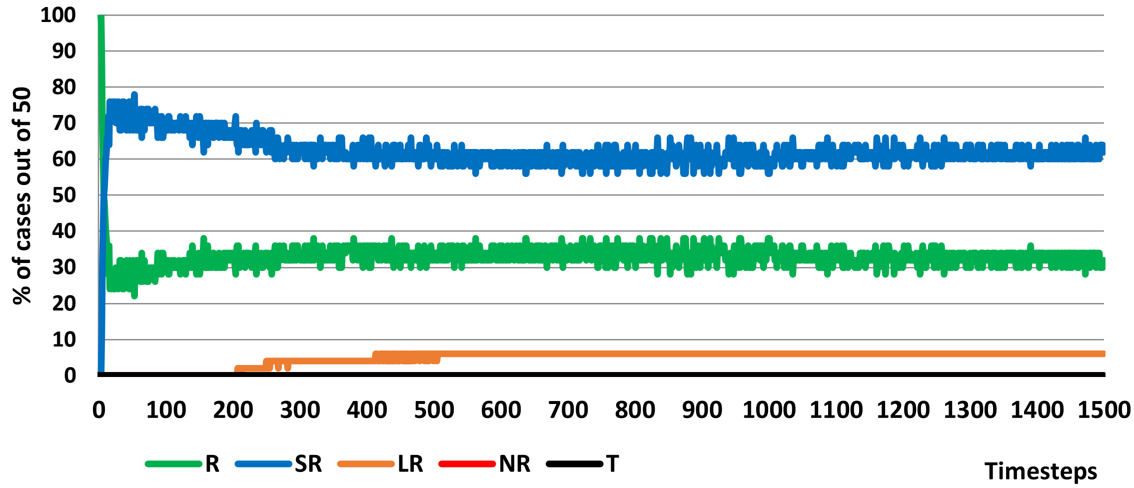

Figure 67. System resilience status under the No-management (NM) system (NCET: 10, NRT: 100

CHAPTER SIX: CONCLUSION AND DISCUSSION

This research explores the bottom-up resilience status of the Urmia Lake Basin (ULB) as one of the world's unique biosphere that has gone through a drastic drought process, which led to the destruction of the lake's integrity and function. The Urmia Lake Restoration Program (ULRP) was launched as a national priority plan in 2014. Considering the complexity of ULB, it is needed for any restoration program, including ULRP, to address the resiliency of the ULB as a SES. Meanwhile, people on the ground are diverse enough to believe that they could have done better than the Controlling Management (CM) corrupted system. Therefore, it is necessary to study the resilience as the capacity of the system and the capacity of the individuals in resilience studies of the ULB. Resilience is commonly identified as the capacity of social-ecological systems (SESs) to retain their structures and functions after receiving shocks and disturbances. Resilience is characterized by the capacities of absorbing disturbances, self-organization, learning, and adapting. Moreover, psychological studies identify the resilience of individuals as the positive adaptation and transformation with the process of absorbing shocks and adapt to new situations by individuals despite experiencing the significant adversity (Matin and Tylor, 2015). To explore the resilience status of the ULB, this research addresses some of the issues in resilience-thinking for the SESs and departs from the dominant established resilience studies of SESs under three conceptual, methodological, and contextual categories.

Conceptually, this research addresses two issues in resilience studies. It drops the duality of ecology and human in resilience studies by taking an integrated approach. I used Agent-Based Modeling (ABM) to capture the nested dynamics within and between the social and ecological subsystems. Also, in this research resilience is considered as the property of individuals as well as the entire system. In the model, the inherited resilience status of ecological individuals plays role in holding or releasing disturbances, and the resilience status of individuals in the social subsystem contributes to adapting to the changes through self-organization and learning. The resilience status of individuals in the social subsystem changes according to the results of the adaptation process.

Using ABM enables this research to employ both aspects of its conceptual hypothesis of integrative bottom-up approach and considering resilience as the property of individuals and the entire system. It also enables this research to move contextually beyond the well-established management system and includes the political power-based corruption situation. In this research, the resilience status of the ULB is captured under three types of management systems: No-management (NM), Controlling Management (CM), and Resilience-building (RB). Figure 68, Figure 69, and **Error! Reference source not found.** that compare the process changing of the resilience status of the ULB and the individuals in the social subsystem under three management systems, support the findings and conclusions of this chapter. Each of these figures is a combination of two previously presented figures in Chapter Five.

The findings of the research indicate that the resilience status in the ULB is uncertain and unpredictable. The resilience status of the ULB is better under the No-management (NM) than Controlling Management (CM). Under the No-management (NM) system, the resilience status of the ULB moves between No-resilient (NR) with 46%, Low-resilient (LR) with 26%, and Semi-resilient (SR) with 22%. The ULB does not present any Resilient (R) state, and the possibility of Transferred (T) status is 6%. The findings show that ecological resilience capacity individually and collectively plays a major role in the system resilience at the early stage of changes in the system. Besides the other parameters, ecological individuals with higher resilience statuses could hold disturbances from releasing and flowing into the network and affecting the larger areas. The human individuals' choices of land utilization, which are based on the learning from the experiences and self-organization, support the ecological resilience capacity by increasing the quality of land units. The resilience status of human individuals affects their choices for changing the land use type and self-organization. When the quality of land units is deeply diminished, the efforts by land-owner agents and their neighboring groups cannot prevent the expansion of disturbances, which exponentially grow. The persistence of this process increases the pressure of disturbances beyond the ecological individual resilience capacity and the disturbances are released by those with the lower ecological resilience capacity, affect the quality of land units, and limit the ability of individuals of the social subsystem to manage their land units. The continuation of this process negatively affects the system resilience, moving away from system resilient towards Semi-resilient (SR), Low-resilient (LR), Not-resilient (NR), and Transferred (T) state and stabilizes its status in one of these states. In other words, as the disturbances to the system exponentially grow, the system gradually loses its structure and function, decreasing the population and the productivity of lands.

However, the findings show that the resilience of the system and individuals do not always move in the same direction. When the system gradually loses its resilience and the population decreases, the individuals are becoming polarized for their resilience status, and gradually the number of individuals at the extremes increases and the number of individuals with resilience status in the middle, who are resilient (r) and resilient-cooperating (rc), decreases. The difference between the two poles is that the resilient agents with the leading state (rl) survive and lead but the agents with low-resilient (lr) and not-resilient (nr) status are forced to leave. This affects the system's resilience status for losing its structure because of decreasing the population and losing the productivity of land units. This is a main general mechanism.

As this process supports the conclusion that the resilience of the system and the individuals do not always move in the same direction, it also, concludes that the resilience status of a system does not reflect the resilience of individuals of the subsystems, and the resilience of the system cannot be reduced to the resilience of the individuals. These conclusions support the importance of understanding the resilience status of individuals of both social and ecological subsystems of a SES, and how they change and affect the resilience status as a system. In other words, in resilience studies of the ULB, it is important to study the resilience states of individuals of both social and ecological subsystems Therefore, it can be concluded that how important it is to consider resilience as the property of individuals as well as the entire system.

This conclusion also is supported under the Resilience-building management (RB) management system. Under the RB system, the resilience status of the ULB stays at the Resilient (R) state and continues at this state over time. However, improving the resilience status of the land-owner agents to the highest state of being the resilient-leading (rl) moves slower than the system's resilience and takes a longer time in comparison with the changes in the system's resilience. This management system prevents anyone from dropping to the state of not-resilient (nr). All these processes occur for the approach and method of resilience-building in this management system and systematic fighting against corruption. In the RB management system, the service-provider agents take care of the land units that are not only affected by the disturbances but also, potentially at the risk. Moreover, the service-provider agents take care of vulnerable land-owner agents and support them. This process findings indicate how it is important to monitor the resilience status of the entire system as well as the individual's resilience to understand how they change as a result of constant dynamics within the system. Ignoring the individuals' resilience status may result in stopping the services to support individuals when the system is in its Resilience (R) state. Then, the system starts to lose its resiliency.

Comparing the Controlling Management (CM) system with the No-management (NM) system, the research concludes that the ULB presents better system resilience status under the NM. Under the Controlling Management (CM) system, the ULB presents the high possibility of a Transferred (T) state with 64% and Not-resilient (NR) with 32%. The ULB does not present any indications of Resilient (R) status. The Semi-resilient (SR) state is the lowest possibility of the system resilience status. Under the Controlling Management (CM), the ULB presents a deeper polarization in the resilience status of individuals in comparison with the No-management (NM) system. These findings support the statement that the ULB could retain its resilience capacity without any current management system, which is controlling. The individuals under the NM system freely adapt to the changes through learning and self-organization, which could help the ULB to stay more resilient.

Building on the achievements of this research, two types of further researches at two different scales are suggested. First, a resilience study of one of the sub-basins of the ULB with a participatory integrated Agent-Based Modeling with GIS to discover more details about the ecological, social, and entire sub-basin resilience status with data from the ground. This small scale with detail information would assist to adjust the current research. Second, the larger scale of resilience study of social-ecological systems is needed to abstract the knowledge of resilience status of ecological, social, and entire system beyond the borders. The large scale study could cover more diverse social-ecological cases that enables the ABM to cover the broader parameters, rules, and procedures that reflect the real-world situation. For example, the corruption system in this research is based on knowledge of the country and ULB management system. Understanding and modeling the political conflict and power-based corruption in a wider range of situations and include much detailed organizational information will contribute to the model reflecting the real world. This further research of covering the larger case studies makes the model capable of being close to general theory. These two further research areas can use real-world policy-making situations for ABM because it is one of the deficiencies of applying ABM in SESs and resilience-building studies.

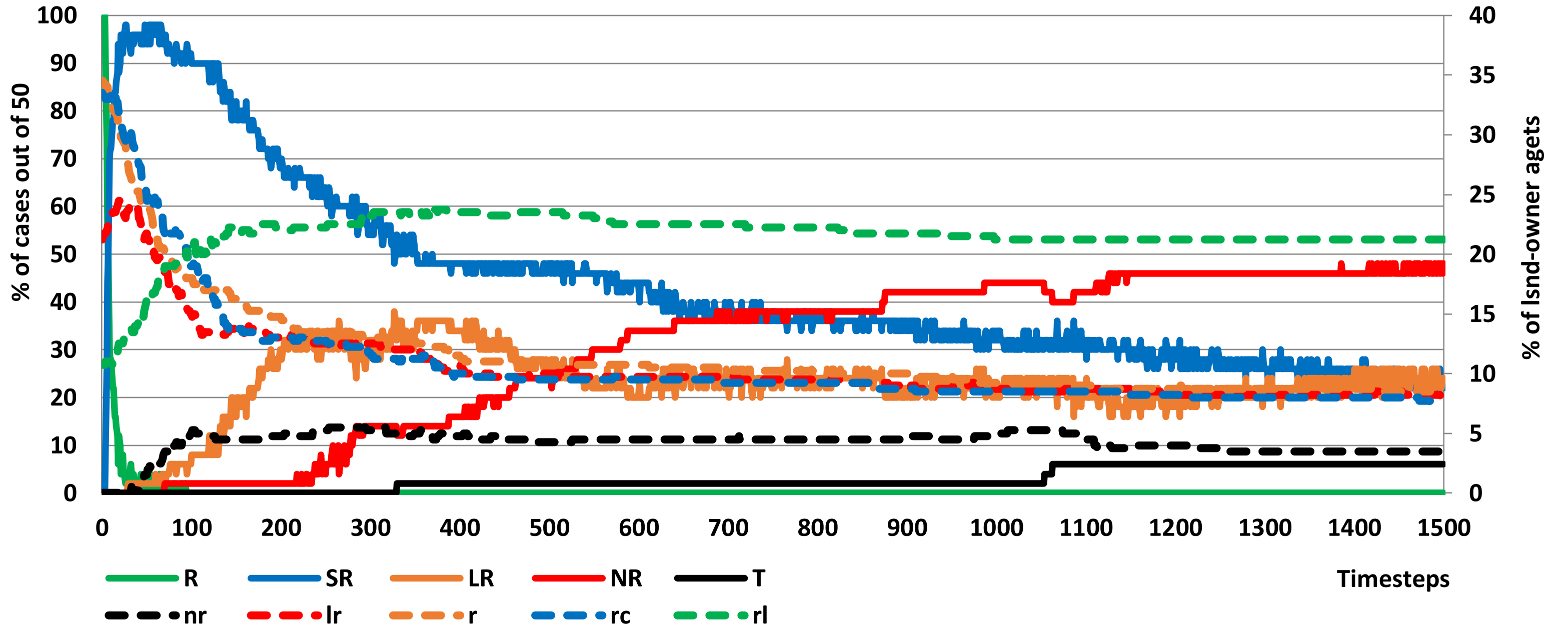

Figure 68. System resilience status (solid lines) and resilience status of land-owner agents (dotted lines) under the No-management (NM) system

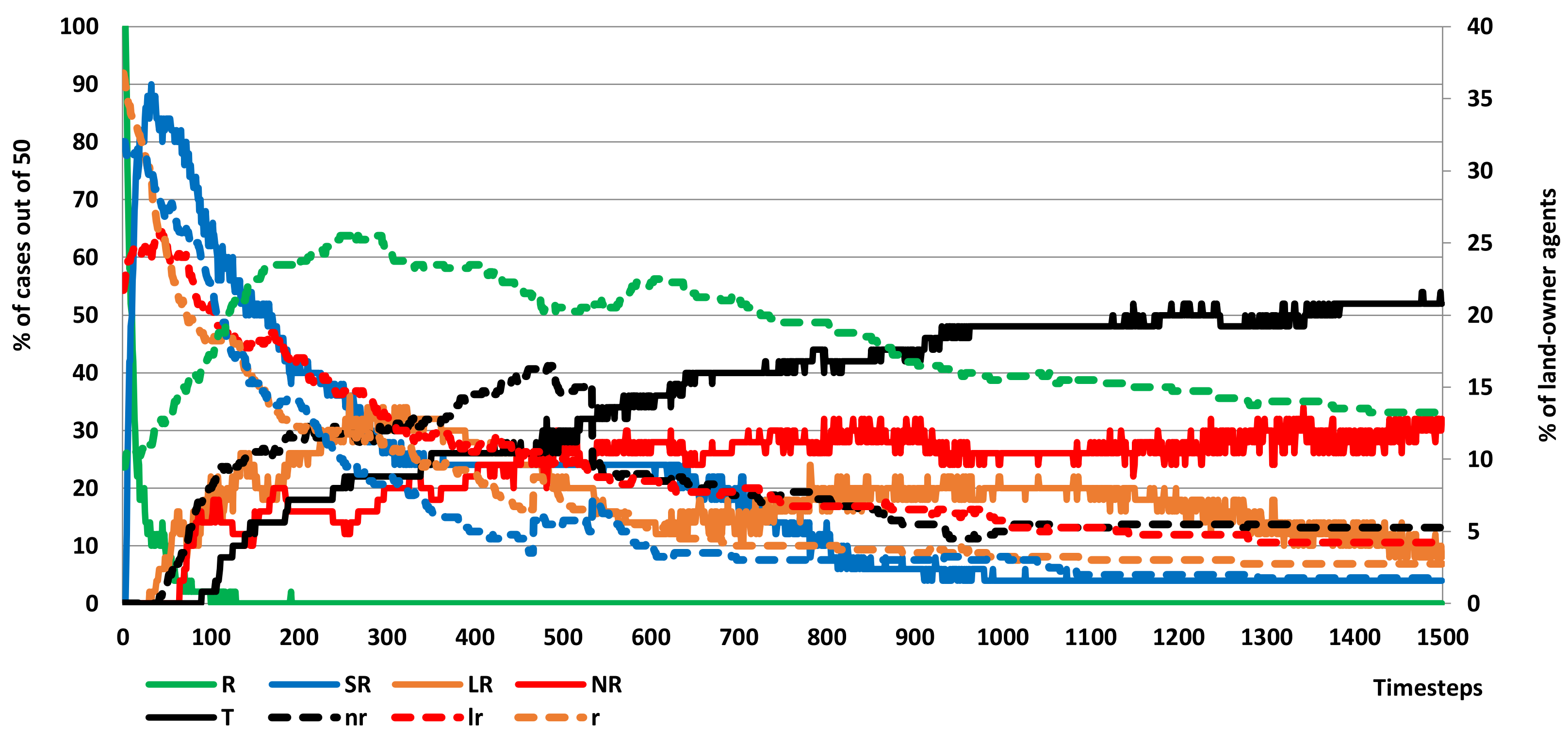

Figure 69. System resilience status (solid lines) and resilience status of land-owner agents (dotted lines) under the Controlling Management (CM) system

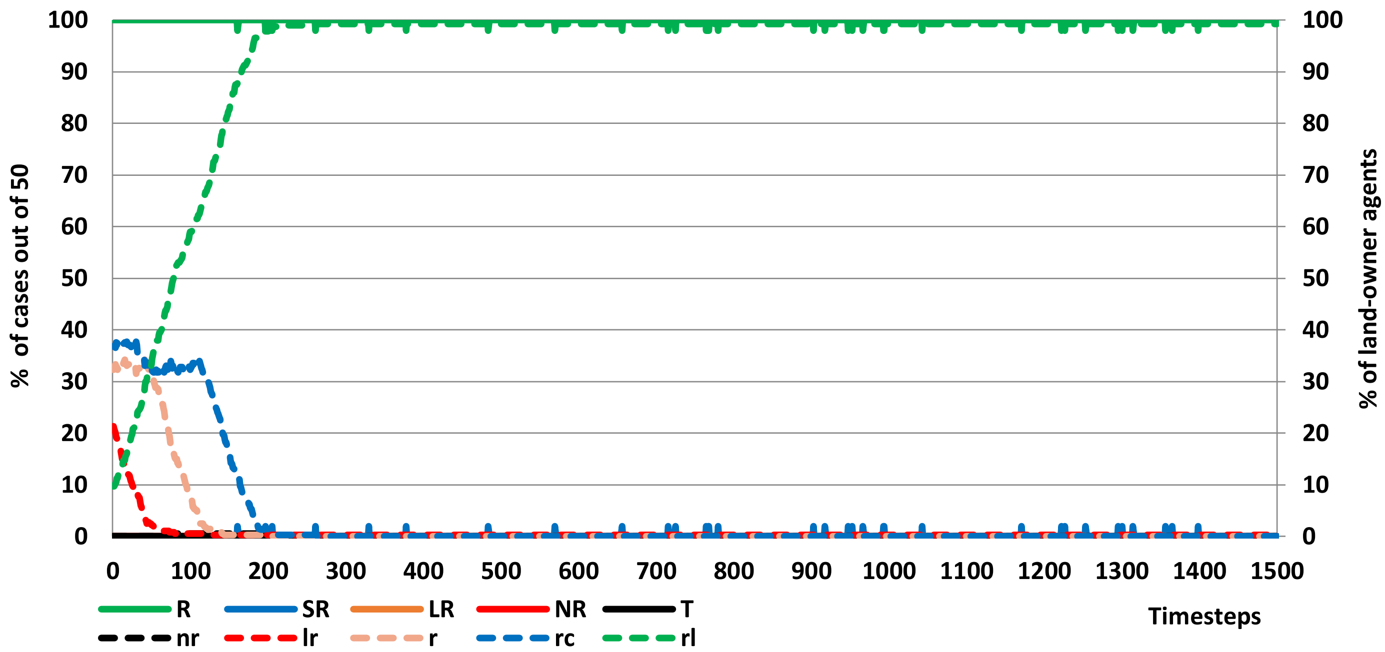

Figure 70. System resilience status (solid lines) and resilience status of land-owner agents (dotted lines) under Resilience-building (RB) system

APPENDIX

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BIOGRAPHY

Farzaneh Davari graduated from Kharazmi High School, Tehran, Iran, in 1980. She received her Bachelor of Science in Social Sciences from Tehran University in 1984, and Master of Science in Socio-economic Information for Natural Resource Management form the International Institute for Geo-information Science and Earth Observation (ITC) in the Netherlands in1998. As a social science researcher and instructor, she has worked in diverse fields, including agriculture, health, and conflict, with the governments and NGOs, and academia. In the past three years, while she was studying for her Ph.D. degree. she was awarded to develop and teach the graduate level course of Decision-making in Complex Environment in School of Public Policy and International Affairs in Virginia Tech.