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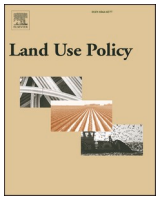

Pathways for improving rangeland governance under constraining land tenure systems: Application of a participatory Bayesian Belief approach.

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ABSTRACT

This paper analyzes the complex relationships of factors influencing rangeland governance in the arid areas. A Bayesian Belief Network (BBN) model was developed in a participatory way to illustrate and assess the weight of a combination of environmental, social and institutional factors enabling the achievement of strengthened rangeland governance at a local level. The Bayesian model was applied in Tataouine situated in south of Tunisia. A complex diagram was built in a participatory way to illustrate the most important interactions between rangeland socioecological system components. Then, a BBN model was applied for a predictive purpose, by inserting evidence conditional probabilities on the most frequent land tenure systems in the region, and thus exploring pathways to improve rangeland governance under each of these systems. Results show that overall improvement of rangeland governance in the study area is highly related to the type of tenure system, performances of farmers organizations, clarification of boundaries between neighboring rangelands, and diversification of the production systems in place by including other agricultural activities in addition to pastoralism. Pastoral areas with tenure systems characterized by combined grazing of private and collective rangelands were revealed to be the most constraining for successful rangeland governance. However, even under such tenure system, the improvement of a set of institutional attributes, especially in relation to the empowerment of farmers organizations can help improving local governance.

1. Introduction

In many of the dry areas, rangelands are facing significant challenges making them highly vulnerable to severe degradation (Nefzaoui and Ben Salem 2011). The result is lower productive capacity of pastural lands, due to the transformation of ecosystem and loss of biodiversity. Tunisia has 4,8 million hectares of rangelands, which represents half of the total agricultural area of the country. Rangelands located in arid areas represent nearly 80 % of the total pastures and provide many goods and services necessary for the local rural populations and beyond.

Many factors and challenges are creating dynamics for resource degradation and transformation in rangeland systems (Rhouma and Souissi, 2004) including social pressures (employment and entrepreneurship in the livestock sector), economic (lack of off-farm economic opportunities for pastoral communities), in addition to climate change and desertification. The increase of the number of livestock heads grazing rangelands combined with the lack of efficient animal feeding strategies and alternatives in the dry areas further aggravated this problem. As a response, policy makers in Tunisia invested in major pastoral development programs which aimed at strengthening farmers organizations and pastoral infrastructure to help with the implementation of rangeland ecological restoration programs. Results and achievements of these programs in terms of rangeland resting and restoration were under expectations (IFAD, 2019). Many authors (Davies et al., 2017; Robinson et al., 2017) referred to the lack of good governance, lack of coordination across local and regional stakeholders, in addition to the co-existence of many intervening actors with overlapping responsibilities as major reasons for these low performances. They further suggest that understanding the relationships among the institutions and organizations in a given pastoral space unit, in addition to governance power distributions and how they are exercised are key elements for successful implementation of rangeland restoration programs.

In addition, most of the Tunisian rangelands (64 %) have a collective

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land tenure status, i.e. these are owned and managed collectively by pastoral communities. This status causes additional difficulties with regard to its land governance (William et al., 2003). The land privatization process will not lead to economic growth and development if not well designed within the overall land tenure and other formal and customary contexts of given communities. In the past two decades, literature development in relation to land tenure has evolved from a focus on private titling and individual tenure to the study of diversity and evolvement of land "tenure security" under collective and customary tenure regimes not enumerated in formal tenure law (Deininger, 2003; Rignall and Kusunose, 2018). In another word, it is important to explore how pastoral actors could overcome rigid tenure systems through enhanced governance mechanisms to improve their social and economic opportunities.

Accordingly, the objective of this paper is to explore, assess, and provide a conceptual and empirical framework for the analysis and identification of drivers of good local rangeland governance. We aim to use these findings to provide feasible recommendations which can guide public investments in enabling environments for rangeland sustainability even under unfavorable tenure systems.

Natural resource governance can be defined as the norms, institutions and processes that determine how power and responsibilities over natural resources are exercised, how decisions are taken, and how actors participate and benefit from the resource (Graham et al., 2003; Springer et al., 2021). In a more practical way, governance further refers to the set of regulatory processes, mechanisms and organizations (Lemos and Agrawal, 2006) which are influencing actions and their respective economic, social and environmental outcomes (Lemos and Agrawal, 2006; Ravnborg and Gómez, 2015). Governance outcomes can also be shaped through nonorganizational institutional mechanisms (such as market incentives and self-regulatory processes) (Lemos and Agrawal, 2006). In the specific case of collective rangelands, governance structures are highly intricated within land tenure systems which are framing the way stakeholders and communities are interacting and taking joint decisions. However, understanding the functional effects of socioeconomic, environmental, and institutional drivers on the success of rangeland governance, and thus on the rehabilitation and restoration of this resource, needs appropriate system research framework and complex systems analysis methodologies and approaches that can integrate knowledge from different disciplines into a holistic integrated framework allowing better characterization of rangeland governance structure and failures.

Given that governance is affected by a complex combination of biophysical, socioeconomic and institutional factors, we then opted for a socioecological conceptualization of rangelands, supported by a Bayesian approach allowing to integrate data of different background into a unique modeling framework. We particularly use the Bayesian Belief Networks (BBN) to draw complex causal relationships through probability distributions (Heckerman et al., 1995, Krieg, 2001) of governance states and its related drivers. The application of BBN in this study also aims at contributing to the conceptual development of methodological tools adapted to system research particularly for the case of rangeland socioecological systems.

The remaining of the paper provides a quick highlight of the institutional background in the rangeland socioecological systems of Tunisia; the methodological approach used to assess current states of rangeland governance in the study area; the main obtained results and finally some guidance and policy recommendations building on the obtained results.

1.1. Institutional settings of rangelands in South Tunisia

1.1.1. Actors and institutions

In the beginning of the century, traditional institutions, called "Myâad", ensured the good management and control of rangelands. They held effective power as they were composed of tribes' leaders (representatives of land owners), who were continuously meeting to decide about grazing management arrangements and options in collective rangelands Gamoun et al. (2018)). During the French occupation of Tunisia, the Myâad evolved into a more official and organized structure called "Land Management Council" (LMCs). The LMC mainly included landowners who constantly meet to take decisions about access and use of these rangelands by different third parties.

In 1956, after independence, the decentralization process of natural resources management was introduced to the country. The Tunisian government has further encouraged the creation of formal farmers associations (rather close to the structure of Community-based-organizations) nowadays called *Groupement de Développement Agricole* (GDA[1]). The creation of the GDAs was justified by the fact that land users are usually part of a larger landowners' community, and thus more inclusive coordination among these users is needed. Local GDAs assure and control the access of farmers to rangelands and provide an organized opportunity for collective actions regarding the preservation and restoration of the pasture areas under their mandate. However, GDAs usually need to coordinate with the LMCs and get their approval for some of their investment and management programs, which is not always easy to coordinate and obtain. This paper aims at analyzing and characterizing the scope and effect of this organizational complexity on rangeland governance. Finally, public administration's role in rangelands management remains mostly related to the implementation of public investments in rural pastoral areas, provision of extension services, control of the excessive use of rangelands, and the coordination between different, local and regional actors, for larger restoration programs.

1.1.2. Tenure systems

In south Tunisia, the existing rangeland tenure systems include the private tenure, also known as "Melk[2]", collective land tenure, and the public land tenure. Under private tenure systems, the land belongs to a single person (individual), a very small group of people (generally a 'large family, also called '*Lahma*'), or a corporate body such as a commercial entity or even non-profit organization (Ben Amara, 1991). The rights of use, control and decision making over the exploitation of the land, goes to the landowners. These rights also include decisions for property transfer through land market or inheritance. However, some of these property attributes might be affected by communal (sometimes informal) rules even if the land is privately owned (See Fig. 1).

The second type refers to collective rangelands which are owned and managed by a given community (or also called a 'tribe'). The rangeland belongs and is used for the benefit of all the members. Within this communal framework, individual families have the right to use the land, according to internal rules defined by the community representatives. Mutual access of pastoralists from neighboring tribes to these rangelands is usually allowed. It helps the communities cope with climate variability by jointly using the most productive land each year. Practically, different tribes are having joint agreements with one or more other far away tribes to mutually exchange land for grazing depending on annual rainfall in both areas (see Fig. 2). Finally, public rangelands are under public ownership (supervised by the "Forest department" of the Ministry of Agriculture) and are usually located in difficult and harsh desertic conditions, thus used by many tribes without proper claim of property. Apart from the control of public agencies, no specific institution currently manages these lands, and therefore this land remained used on an open access mode. In practice, farmers are combining the use

[1] GDA: Groupement de Développement Agricoles; similar of farmers associations (or also Community Based Organizations)

[2] According to Ben Amara (1991), "the Melk is determined by the extent of the property, its consistency and its nature. It derives its basis for a possession in good faith, peaceful, public, continuous and prolonged for at least ten years. These items can be authenticated by an act called Melkia which establishes the property. "

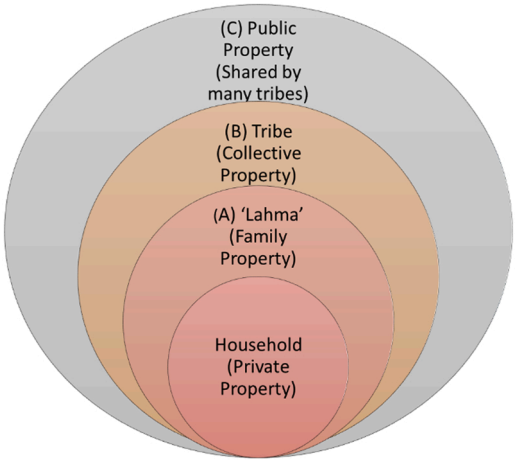

Fig. 1. Embedded property rights for rangeland ownership in the study area *(HH: household property; A: Lahma (or large family) property; B: tribe property; and C: public property)*.

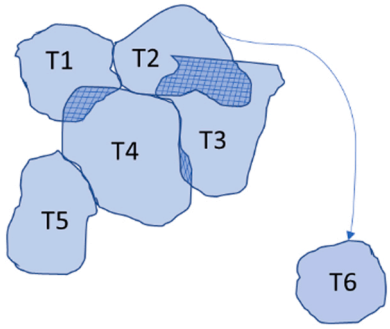

Fig. 2. Tribe (collective) ownership and overlapping ownership areas of rangelands (*T: tribes; Hatched spots: areas of overlapping and conflictual property rights*).

(grazing) of different type of rangeland through various access rights. Some pastoralists are grazing only on collective lands, others are exclusively using their private rangelands, while others are combining the grazing of both collective and private rangelands (Nasr et Mares, 2004; Ben Saad et al., 2010).

1.2. Conceptual framework

1.2.1. Rangelands as socio-ecological systems (SES)

In this study we test the hypothesis that a given rangeland governance state is an outcome of the interaction of many social, institutional and environmental factors. Having a good rangeland governance in a given area can be affected by some or many of these factors and remains always difficult to predict. Within this framework, conceptual difficulties which we try to handle in this paper came from two main sources. Firstly, it is always difficult to qualify a given governance state due to the lack of appropriate governance indicators for the specific case of rangelands, which can easily be observed and effectively assessed by local stakeholders in different contexts. Secondly, the causality relationships leading to a given governance outcome would be highly complex and sometimes context specific thus leading to the need to define rangelands as **Socio-Ecological Systems (SES)** and adapt this concept to given local conditions. Participatory and multidisciplinary approaches to draw these relations through consultations with local stakeholders and experts can help drawing the different functional relationships within these rangeland SES (See Fig. 3).

Rangelands are providing a wide range of social, economic, and ecological services and can be considered as specific SES. To characterise the interactions within this SES, we assume that agro-ecologies[3] are a combination of biophysically defined scales deeply related to socially constructed spaces (Thiel et al., 2015). Rangeland agro-ecological space describes the spatial scale of biophysical interdependencies between processes involving the use of natural resources (mainly biomass available for grazing) for livestock production in the dry areas and are delineated by climatic boundaries. Analytically, understanding rangeland agro-ecologies refers to the analysis of inter relations between pastoral and other agricultural farming practices (including grazing, forage, and tree production) and off-site ecological processes, mainly related to climate conditions, soil and land degradation, etc. In SES, institutions are considered to mediate between biophysical interdependencies of actors, as illustrated through trade-offs in ecosystem components, goods and services (Thiel et al., 2015). The institutional dimension of rangeland agro-ecologies describes the scale of social processes that shape specific political, economic and institutional aspects relevant to pastoral and agro-pastoral systems management and decisions (Mollinga et al., 2007). Resource management performances are thus strongly addressed by institutions (including land tenure, local GDAs performances, etc.) or administrative and political processes which will result in given levels of resources sustainability (also considered as construct of "governance" in this study.[4] Thus, the role of factors such as land tenure systems, formal and informal rules regulating access and use of resources, constraints on key livestock input factors, as well as interactions between individuals and communities, need to be considered in an integrated way. Among all of these factors, land tenure remains of high relevance as it outlines the different rights and conditions to use, access and control the resources, along with the rights to transfer (Bambio and Bouayad Agha, 2018). Table. 1.

1.2.2. Bayesian Belief Networks for research on natural resource management

BBN is considered as highly suitable tool for our case study on rangeland SES due to its capacity to assess the influences and interdependencies of different types of factors, and accordingly weightage and ranking of the contributing factors to an "outcome event"(Campbell et al., 2012; Gonzalez-Redin et al., 2016; Kleemann et al., 2018; McNay et al., 2006; Smith et al., 2017). One of its advantages is the possibility to integrate knowledge from Ecology, Economics and Social Sciences (Kleemann et al., 2018; Smith, 2010; Stephenson et al., 2018; Yamada, 2018) within the same analytical decision model and use it to improve policy making.

Another important advantage of BBN is the possibility to cover both subjective probabilities (based on experts' opinions and other minimum data approaches) and probabilities based on real observed data (Marcot et al., 2011, Newton et al., 2007). The flexibility of BBN in gathering several factors and data types considering all stakeholders' information about a large spectrum of functional interactions between natural subsystem and human subsystem within a social-ecological system, endorses the convenience of this method for ourresearch on rangeland governance.

The BBN has been widely used in the study of decision making for natural resources management during the previous decade. This includes studies on impact assessment of management scenario for forests (Gonzalez-Redin et al., 2016; Yamada, 2018), water resources

[3] The " agro " acronym refers to an economic activity (agriculture) which involves a socioeconomic dimension adding to the ecological main attributes of agro-ecologies.

[4] Other studies focusing on the sustainability of rangeland ecology may for example consider "governance" and an input (or component) of the SES, which is not contradictory to our choice for considering "governance" as an outcome of the SES. Such choices are highly dependent to the hypothesis to be tested and to the conceptual frameworks built to do so.

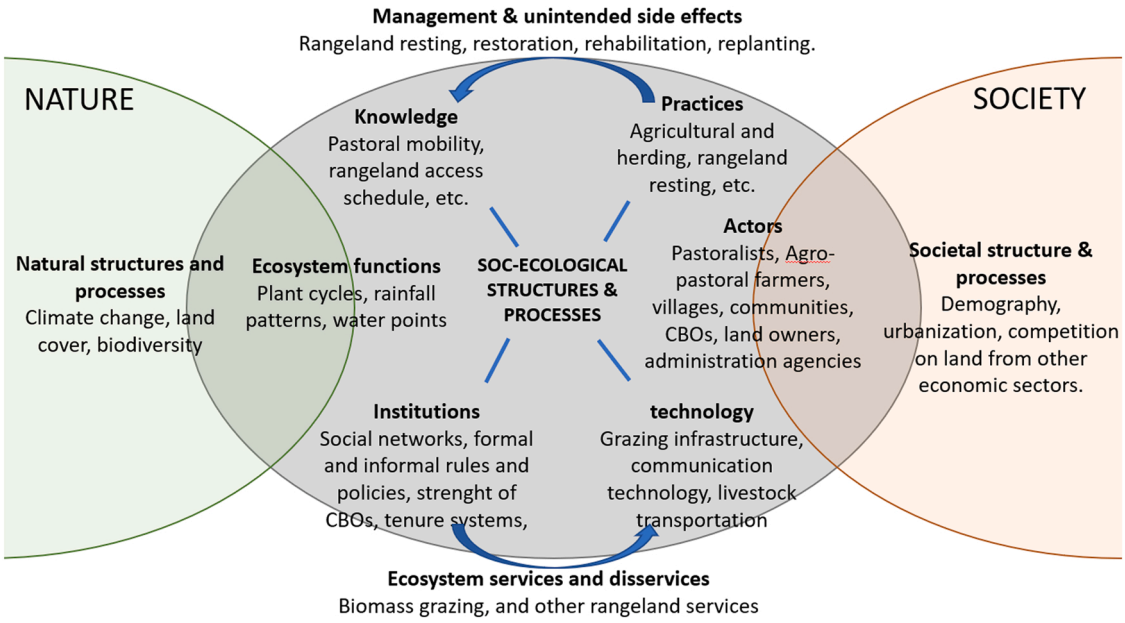

Fig. 3. Conceptualization of the role of rangeland management within a SES context. (adapted from Hummel et al., 2011; and Drees and Liehr, 2015).

Table 1
Indicators used to discretize different governance levels.

Indicators	*Good Governance*	*Acceptable Governance*	*Weak Governance*
The level of satisfaction of local population about the GDA management of community rangeland.	If all these indicators are highly ranked by the interviewed user.	If at least one of these indicators is not highly ranked by the interviewed user.	If two or more indicators is not highly ranked by the interviewed user.
The state of biomass dynamics and the existence of successful rangeland rehabilitation programs.			
The existence and the quality of appropriate grazing infrastructure –watering points, rest umbrellas, etc.			
The coherence (in decision making) between the different administrating groups of the GDA and the LMC*			

* Land Management Council (LMC). Source: Own elaboration

(Castelletti and Soncini-Sessa, 2007; Crossman and Pollino, 2018; Henriksen and Barlebo, 2008; Phan et al., 2016), rangelands (Crossman and Pollino, 2018; Smith, 2010), fisheries (Stephenson et al., 2018), protected areas (Campbell et al., 2012; Gonzalez-Redin et al., 2016; Lohr et al., 2017; Smith et al., 2017), and even land use policies (Kleemann et al., 2018; Mallampalli et al., 2016). BBN has been applied in other rangeland studies including the one of Bashari and Smith (2010) who applied the tool to assess the impact of selective grazing, grazing pressure, and soil nutrition on the rangeland vegetation dynamics. This application is more ecological-oriented and does not focus much on rangeland governance, as does the current study.

Other recent studies such as Yamada (2018) used the BBN to model the relationships between zoning policy, which is considered as a regional forest management method, and individual forestry activities (such as thinning or clear-cutting). BBN can also be linked with other methodologies such as GIS. In their study, Gonzalez-Redin et al. (2016) proposed this integrated methodology to help forest managers evaluate implications and trade-offs between forest production and conservation measures to in forested habitats. Campbell et al. (2012), developed a BBN design, which incorporates different types and sources of data, expert and stakeholder knowledge and datasets from the Western Indian Ocean. The objective of their BBN model was to allow the policy makers and managers assessing the *exante* impact of different marine policies on communities living in Marine Protected Area, marine health, economic output, and social wellbeing. The study confirms the fact that BBN is useful and robust in integrating different environmental, economic, and social impact dimensions.

2. Methods

The methodological framework of the project is illustrated in Fig. 4. Following the BBN methodology, the core of the network's structure[5] must first be developed. The first step to structure relationships within SES is the construction of a graphical network of causality linkages (McCann et al., 2006).

2.1. Multi-stakeholder's approach for the implementation of the BBN

The network structure can be described as logical suite of nodes describing causality between different drivers and their logical consequences (See Fig. 5). To develop this structure, we usually gather experts' knowledge from multidisciplinary focus groups and discussions. The participatory process starts by presenting to the group the target node needed to be modeled (node 1 in Fig. 5), which usually reflects the final causal link (or also the outcome of the considered causality

[5] Which can also be defined as a representation of nodes/linkages as described in Fig. 4.

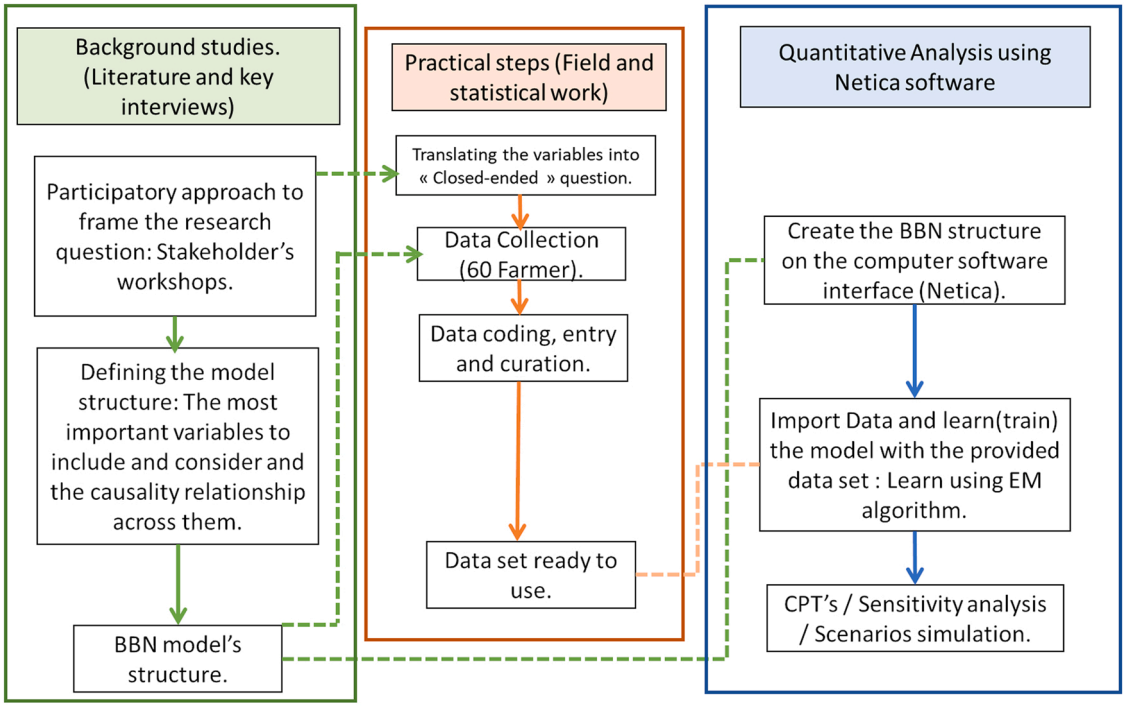

Fig. 4. Methodological framework.

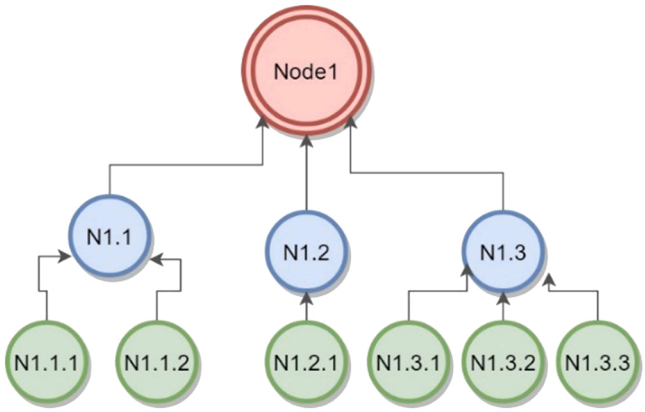

Fig. 5. Conceptualization of a (two-level) BBN structure diagram developed around a selected priority issue "Node 1" (
Source: own elaboration 2019).

network). Node 1 (also called "*child node*"), need to be a discrete variable reflecting the governance outcome of different socioeconomic and environmental interventions in the rangeland SES. One examples can be: "*We do have good rangeland governance in a given rangeland area*" (this variable can take two condition states: yes/no). Once "Node 1″ defined, we then ask participants to agree on three (or more) primary variables (N1.1, N1.2, and N1.3) that directly influence the desirable (and/or undesirable) state of *Node1*. These are also called *parent nodes*, and can be for example: rainfall anomalies, land tenure system, existence of performing land management council, performance of local farmers' organizations (GDA) managing the rangeland area, and the existence of rangeland rehabilitation programs. For each of the cited variables, experts should also provide its desirable and undesirable states. A final iteration for developing a third hierarchical layer of the network structure, would be to ask the expert panel to also identify the variables (N1.1.1, N1.1.2, N1.2.1, N1.3.1, N1.3.2, and N1.3.3) that directly influence these primary variables (N1.1, N1.2, and N1.3).

2.2. BBN design and data collection in Tataouine

To implement the BBN model, we organized two focus groups composed of all relevant stakeholders from the two pastoral regions of Tataouine. The first workshop was conducted early October 2017 in Tataouine. It involved 37 actors from government and farmers organizations including different relevant administrations from the regional offices of the Ministry of Agriculture (researchers (10), CRDA (9), OEP (04)) and local farmers organizations (including Farmers Union members (03), GDA (08), Land Management Councils (02), and a leader farmer (01)). Thus, a total of 14 farmers representatives were attending these meetings.

These participants were selected from the most representative stakeholders. The selection was based on a long process of collaboration in several previous projects and several socioeconomic surveys in the region. The participants have a long experience working with researchers and technicians. The objective of this (expert) meeting was to develop a solid structure of the BBN which reflects the different primary and secondary variables affecting rangeland governance from stakeholder's perspective.

Following this first workshop, we proceeded with a desktop work to further fine-tune the established network. In this step we eliminated and/or reformulated the list of primary and secondary variables in such a way that they can easily be formulated into a questionnaire and can clearly be discretized (See annex 1). During this operation, we tried not to lose the initial suggestions and rationale of stakeholders who defined these variables. Based on the final list of variables to be considered, a short and expressive questionnaire was written to be able to collect and gather field data from local pastoral farmers in the region. A brief section of the questionnaire was included to reflect on the structural characteristics of the surveyed farms (land use/surface, number of livestock and the years of experience of the farmer in the field). The remaining questions were close-ended and directly focused on selecting specific states of primary and secondary variables by each interviewed rangeland users. Field data collection was done in May 2017. The field surveys have been conducted with 60 pastoralists from the region. These were selected based on farming system typology and land tenure systems. The

data collected were coded and cleaned using Excel and early data analysis was carried out using SPSS software.

The second workshop was organized on June 21st, 2018, in Douz (Kebili governorate). This workshop brought together 30 actors from three governorates (Tataouine, Medenine, Kebili), concerned by rangelands governance (Researchers (10), CRDA (6), OEP (3), GDA (3), LMC (3), independent pastoralists (3), UTAP (2). In this workshop, we received feedbacks on early results of the study, and we jointly discussed and validated early policy recommendations.

2.3. Defining rangeland governance as an "outcome event"

The "outcome event" selected (State of rangeland governance) is difficult to be evaluated by rangeland users and will be highly subject to personal subjective judgements of differed interviewed users during the survey implementation. For this reason, we asked rangeland users about governance indicators in their respective areas and then derived the "state of governance" out of these indicators. A predefined discretization of the "state of rangeland governance" has been established based on the indicators defined by the focus group participants (Illustrated in Table 2). It is therefore important to note that only governance indicators than can easily be discretized by users, have been considered as proxies for the current governance classification (See Table 2). Furthermore, some of the redundant indicators mentioned by participants have been prioritized and merged to come up with the final list displayed in Table 2. Users' perceptions about these indicators was assessed on a scale of 0–5.

2.4. Conditional Probability Tables (CPT) calculations and sensitivity analysis in BBN models

After the participatory development of the BBN structure, a data collection step was conducted. Those data were used for the training of the BBN model through the calculation of the "Conditional Probability Tables - CPT". (Marcot et al., 2006, Zhu and McBean, 2007). For each observation, the data can be limited to collecting information about the state of condition (either desirable or undesirable) for each of the nodes defined in the BBN structure (See Fig. 4). The CPT, which presents the quantitative part of information of our BBN model, is a set of conditional probability distributions that define a probability distribution over the output variable given all combinations of values of the input variables included in the Bayesian network. CPT stores every possible combination of the states of the parents. Specific computer software can be used for the calculation of CPTs, after mapping the collected field data into the developed BBN structure, and thus providing a CPT which can be used to define the probability weight of each node on the outcome (Node 1). For the calculation of these probabilities, NETICA (Norsys Software Corp, 2007),[6] the computer software used in this study, uses three main types of algorithms based on Bayes theorem: counting, expectation-maximization (EM) and gradient descent. In this study, the Expectation-Maximization (EM) learning algorithm has been used. The EM algorithm is an efficient iterative method. The algorithm is used to perform maximum likelihood (ML) estimation by learning an initial probabilistic model on the parameters from randomly incomplete data set (Pilla and Lindsay, 2001; Zou and Yue, 2017). In ML estimation, the estimation of the model parameters is determined for which the observed data are the most likely.

Table 2
Land tenure scenarios simulated using the BBN model.

Scenario's components	Condition on Governance Variable	Condition on Land tenure variable LT:
S1: Good rangeland governance in the study area.	Good (CV: 100 %)	-No condition on LT (land Tenure)
S2: Good governance under combined grazing of private and collective rangelands.	Good (CV: 100 %)	P-C (CV: 100 %)
S3: Good governance under exclusive grazing of collective rangelands.	Good (CV: 100 %)	C (CV: 100 %)
S4: Good governance under exclusive grazing of private rangelands.	Good (CV: 100 %)	P (CV: 100 %)

S: Scenario; LT: Land tenure; CV: Condition Value; P-C: combined grazing of private and collective rangelands; C grazing of only collective rangelands; P: grazing of only private rangelands.
Source: Own elaboration

The EM iteration alternates between performing the expectation step (E) and the maximization step (M). The E-step generates a function and compute the probability of the unobserved variables using the current estimates of observed variables using the conditional expectation algorithm. The maximization M-step computes model parameters through maximizing the expected log-likelihood resulted from the E step, believing that the missing data are known. It uses the estimated log-likelihood of the unobserved variables to re-estimate the model parameters. This loop of E and M steps will continue until convergence of the algorithm which is guaranteed to increase the likelihood at each iteration.

The CPT can also be used for a third and final step concerning the simulation of different options and scenarios including test on the structure, sensitivity analysis, etc. Scenario's simulation using BBN can be done by fixing a prior probability of a given influencing variables (by specifying for example a given context which is difficult to change) and checking which state of other variables could slightly enhance the probability of having good rangeland governance.

The Bayes' theorem, a simple formula used for finding conditional probabilities based on certain other probabilities, is at the centre of the mathematical component of a BBN model. (Baynes et al., 2011). The theorem is expressed mathematically by Simon (2006) as follows:

$$P(B \mid A) = P(A \mid B)\, P(B) / P(A).$$

The model tries to tell how often A happens given that B happens P (A|B), When we know: how often B happens given that A happens, also known as the 'posterior' probability of event B P(B|A), the prior probability of A P(A) (how likely A is on its own) and the 'prior' probability of B P(B) (how likely B is on its own, written P(B)).

Further to the calculation of CPTs, a sensitivity analysis is conducted to identify the variables that reveal the most information and influence on a target node. Sensitivity analysis can be performed on any node of the resulting BBN.

A sensitivity analysis allows the determination of the sensitivity of rangeland governance node (target node) to findings in all the other nodes of the model. More specifically, sensitivity analysis allows the identification of the most influencing variables/factors on our target node (Governance) and helps to understand the causality relationships i. e., how the probability outcome of the target node will likely change according to findings at the rest of the model's nodes (Van Putten et al., 2013). These results are obtained through the calculation of mutual information (entropy reduction) values as described in Marcot et al. (2006). The factors are ordered from the most important to the least important using the the reduction scores. Mutual information is a measure of the magnitude with which a finding at one node is expected to alter the beliefs at another node (Korb and Nicholson, 2004). Indicators are used to detect minimum and maximum beliefs (Kjærulff and Madsen, 2008). The Netica software expresses the entropy reduction of the variables as percentages of the total entropy of the target node.

The mutual information of A and *B* is given by (Cai et al., 2013):

$$I(A, B) = -\sum_B \sum_A P(A, B) \log P(A, B)\, P(A)\, P(B).$$

Where *P* (A, *B*) is the joint probability distribution function of *A* and

[6] *NETICA commercial version "5.18" was used for this study (more on Norsys Software Corp, 2007).*

Table 3
Summary of local stakeholder perceptions for enhancing rangeland governance under different land tenure systems (summary from Figs. 9, 10, and 11).

	Private and collective	Collective only	Private only
Relationship between GDA - LMC	Increase	Increase	Neutral
Perception about GDA performance	Strongly Increase	Moderate	Neutral
GDA capacity to raise funds	Increase	Increase	Neutral
GDA president socially acceptable	Increase	Neutral	Moderate
Competition over rangelands	Reduce	Increase	Highly Increase
Well defined boundaries of rangelands	Increase	Highly Increase	Highly Increase
Beneficiary from development projects	Increase	Neutral	Neutral

Source: Own elaboration

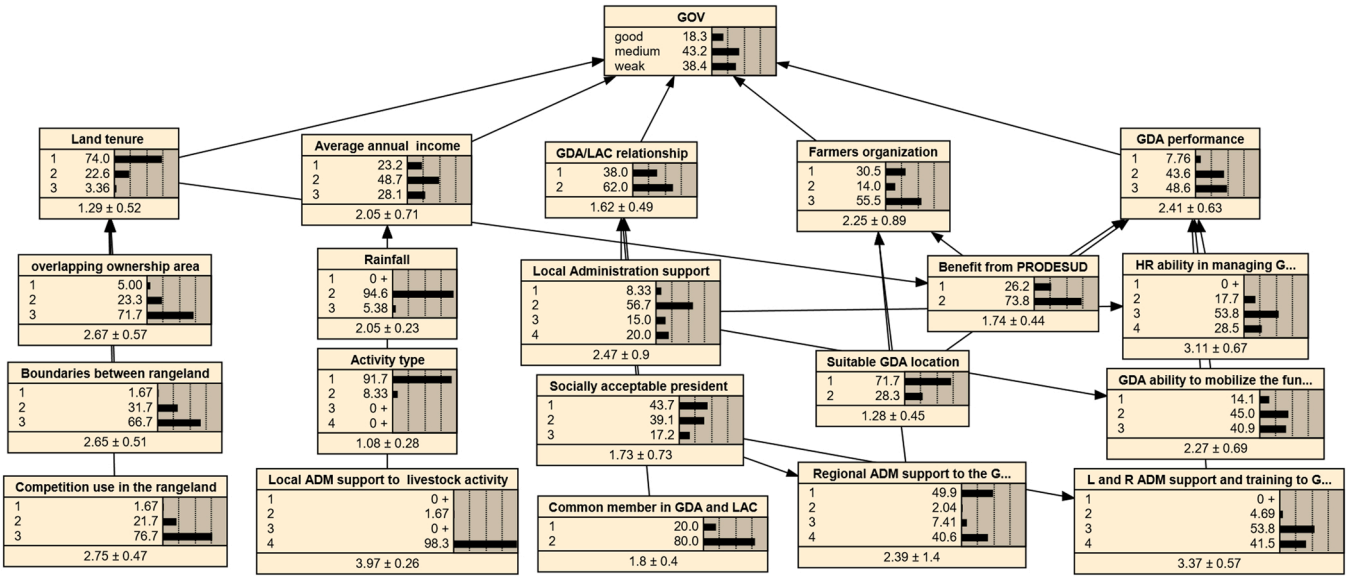

Fig. 6. BBN Network learning Results of Tataouine data (
Source: Own elaboration from Netica software; Abbreviations: GOV: Governance; HR: Human Resources; ADM: Administrative; L: local; R: regional; G: GDA; PRODESUD: Programme de développement agro-pastoral et des initiatives locales dans le Sud-Est).

B, and *P*(*A*) and *P*(*B*) are the marginal probability distribution functions of *A* and *B*.

2.5. Land tenure scenarios for enhancing rangeland governance

In addition to the representation and analysis of rangeland governance, the BBN is used in this study to estimate altering future enhancement of governance in different scenarios. The objective of scenarios analysis is to formulate policy recommendations that can guide public investments in rangeland governance. In another word, we would like to respond to the following type of question (S1) "**what** public interventions are needed if we would like to have 100 % chance of finding "good governance" everywhere in the rangeland areas"? This first scenario will check for prior probabilities which help achieving good rangeland governance without any prior condition on tenure systems. Giving that land tenure systems are difficult to change, we further asked the following question for scenario 2 (S2): "**what** public interventions are needed if we would like to have 100 % chance of finding "good governance" everywhere in the rangeland areas which are grazed under both "private and collective" regimes"? The same reasoning is used for S3, and S4 (See Table 3).

In this first scenario, we fix the target node to "good governance" and explored the different changes occurring on the probability distributions of primary and secondary variables. This will help understanding the key elements on which we have to act if we want to maximize the probability of having "good rangeland governance" in the study area. The same logic will be followed for the remaining three analytical scenarios. To visualize results of those scenarios we calculated the percentage of change of probabilities in each node compared to its prior probabilities. The percentages of change will be calculated as following: [(Posterior probability – Prior probability) / Prior probability] * 100.

3. Results

3.1. Rangeland governance: conditional probabilities and sensitivity results

The resulting network structure from the participatory discussion on rangeland governance in Tataouine is presented in Fig. 6. Probability distributions of the variable states (see boxes of Fig. 6) were calculated

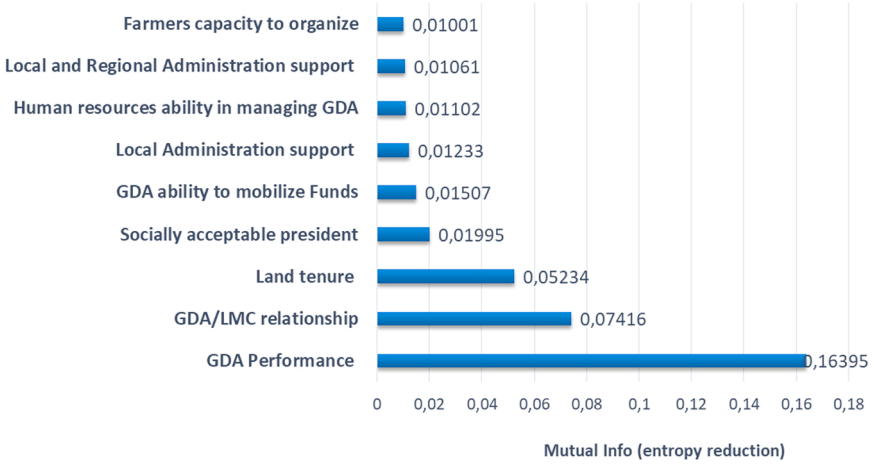

Fig. 7. Sensitivity analysis results of the most influencing variables on rangeland governance in Tataouine (
Source: Own elaboration from Netica software).

based on field data and indicate that more than 80 % of interviewed farmers consider local rangeland governance, in their areas, as weak to medium. About 74 % of farmers in the considered sample stated they are grazing in both private and collective rangelands, while 22.6 % are exclusively grazing collective rangelands, and only 3.3 % are grazing private lands. Most farmers in the sample (66.7 %) confirm the lack of clarity on rangeland ownership boundaries in their pastoral areas. About 76.7 % indicated that there is no competition on rangelands use between pastoral and other (economic and agricultural) usages. Performances of local farmers associations (GDA) is perceived as low by 48.6 % of farmers. Only 7.76 % of farmers believe their associations are well performing. The weak capacity to mobilize funds (40.9 % of responses), the weak management capacity of human resources of the GDA (82.3 % of responses) and the weak local and regional administration support and training to GDAs are the main reasons behind low GDA performance. About 62 % of the participants further claimed that the relationship between GDA and LMC is conflictual in their rangeland area. It is also important to note that average annual income of farmers was between 5000 TND[7] and 10,000 TND for 48.7 % of the interviewed farmers. Further results can be read in Fig. 6 and annex 1 (name of variables and their respective states of nature).

A sensitivity analysis of these identified variables was conducted and presented in Fig. 7. Fig. 6 shows that "farmers' perceptions about their respective GDA performance" has the greatest influencing degree on the governance node with a mutual information (MI) value of 0.16 (16 %), followed by the "level of synergy between GDA and LMC" (with about 0.07: 8 %). Other variables such as, land tenure, existence of a socially accepted president of GDA and GDA ability to mobilize funds, are also among the most significant target nodes to which the governance state is sensitive, with an MI values of 0.05, 0.019 and 0.015, respectively.

3.2. Pathways for enhancing rangeland governance in Tataouine

Our analysis included analyzing different scenarios to identify pathways for enhancing rangeland governance under different conditions and constraining factors. This first section reports about the first scenario S1 (see Table 2) where we fixed a posterior condition of 100 % probability for good rangeland governance and then take note of the percentages of change that occur on the different parent nodes of the network. Results displayed in Fig. 7 reveals that enhancing rangeland governance in the study requires the decrease of the frequency (probability) of having rangeland areas where farmers are combining the grazing of both private and collective lands. These are areas where conflicts are dominant compared to other areas with different tenure systems, and they do need enhanced management practices. Overall, good rangeland governance in South Tunisia (including all tenure systems) requires a reduction of conflicts between GDA and LMC, and most importantly an improvement of GDA performances (see Fig. 8) (frequency of highly performing GDAs is suggested to increase with 110 % compared to the status-quo situation shown in Fig. 6). Fig. 7 also shows that, for enhancing rangeland governance, it is important to increase the probability of having rangeland areas with mixed pastoral and other agricultural activities. This indicates that agro-pastoral systems would have better governance results compared to purely pastoral systems. It is also important to well define the boundaries between neighboring rangeland areas, to increase the level of farmers income, as well as their capacity to self-organize (Fig. 8).

3.3. Rangeland governance under different land tenure systems

The remaining three scenarios are looking at pathways for enhancing rangeland governance under specific land tenure systems. The second scenario is dealing with situations where farmers are combining grazing both private and collective lands at the same time.

Fig. 9 shows that good rangeland governance under such conditions requires to act particularly on enhancing GDA performances (suggest increasing the incidence of having well performing GDA with more than 200 %). Within this perspective, it is beneficial to increase the capacity of GDAs to raise additional funds and reduce the probability of having GDA presidents which are not well accepted by their communities. The model also suggests that good governance of rangelands under such tenure systems requires a decrease (by −55.68 %) of the probability of having strong competition on rangelands between pastoralism and other uses. Fig. 8 also suggests that non-clear boundaries are more favorable for good governance in these areas. Finally, it is also suggested that farmers income, their capacity for self-organization, in addition to additional development investments should further be promoted.

Under collective land tenure systems, results in Fig. 10 show that better governance can be achieved through enhanced coordination between GDA and LMC (increase the probability of having good relationship between GDA and LMC). Other GDA related variables refer to the GDA capacity to rise funds (Fig. 9). It is also suggested in Fig. 9 that the incidence of having beneficiary communities from infrastructural and development investments should decrease (pull-back effects related

[7] 1 USD = 2.5 TND at the time of the survey (period: May 2017).

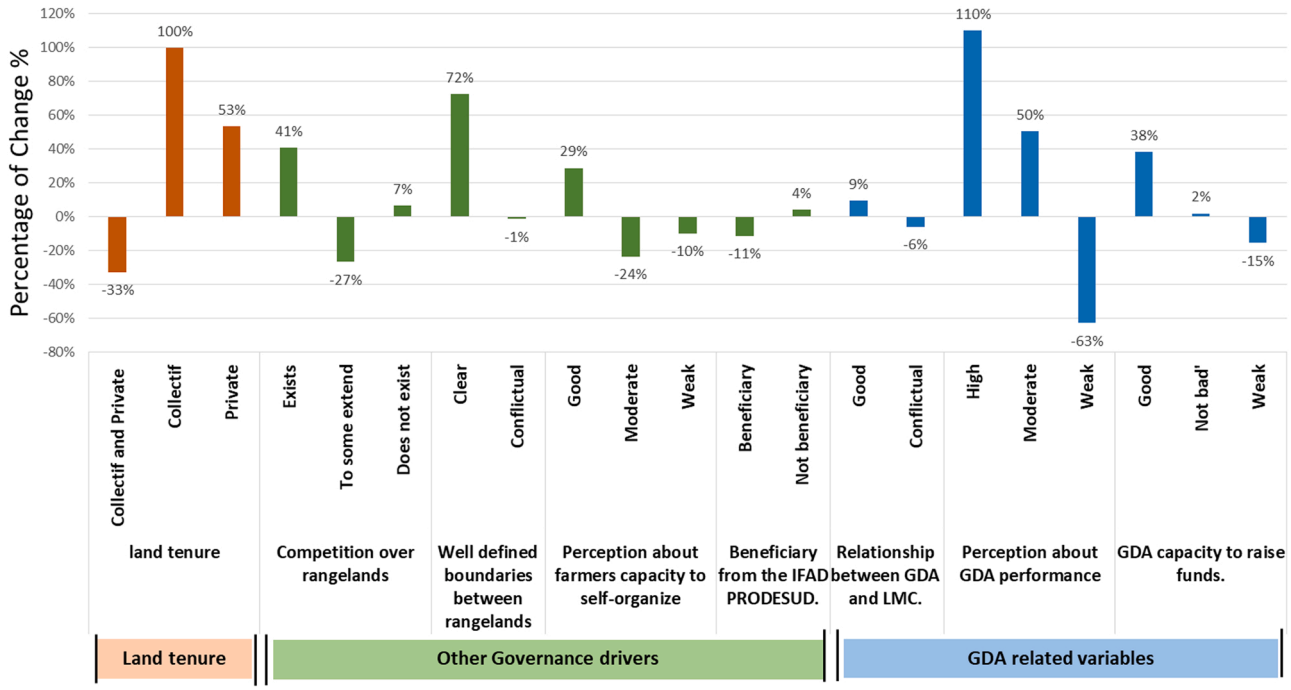

Fig. 8. Changes of conditional probabilities of the most relevant governance enabling variables (scenario 1 in Table 2).
Source: Own elaboration.

to the PRODESUD[8] investments) in order to enhance rangeland governance. This means that non-beneficiary communities have better perception about their local rangeland governance (compared to beneficiary communities). We suggested to increase the probability of having rangeland areas where pastoralism is conducted with other economic activities suggesting the need for transition towards agro-pastoral systems with diversified economic alternatives. The problem of boundaries between collective rangelands and their neighboring areas is also significant. Results also suggest that enhancing farmers capacity for self-organization will result in better rangeland governance in these areas.

The last scenario is looking at pathways for enhancing rangeland governance under private land tenure systems. Findings suggests that good governance under such system is not necessarily related to the performances of GDA (Fig. 11). The most important drivers that need to increase in incidence in order to have good rangeland governance under tenure systems are the competition over rangelands (+ 250 %), the clarity of boundaries between lands (+150 %), and the capacity of farmers to self-organize (+41 %). Like collective rangelands, farmers grazing on private lands have better perception of rangeland governance when the production systems are more diversified involving other usages of rangeland in addition to pastoralism. It is thus clear that there is a need to identify additional income generation activities in both private and collective areas.

4. Discussions

Findings of this study are showing that improvement of rangeland governance in the study area is highly related to the type of tenure system ownership, enhancement of the role and performances of farmers organizations, and increasing diversification of the rangeland production systems in place. The most constraining tenure system for good rangeland governance was the system where farmers are combining the grazing of both private and collective rangelands. Collective or individual rights from customary land tenure in developing countries are usually based on clan or family affiliations and enjoying these rights would obeys complex social rules (Hesse et al., 2013; Bambio and Bouayad Agha, 2018). When these two tenure systems are embedded in the same area, property rights attributes became blurring and lead to persistent conflicts within the communities, which will in turn affect the state of resource governance and sustainability.

The study has further shown that collective land status are the most favorable for good rangeland governance, which is in line with Ostrom principles (Ostrom, 1990) for common resources management. Under the most constraining tenure system (private ownership embedded into larger community property), stakeholders rather prefer unclear boundaries, which have been found to be more favorable for good governance in this context. This can be explained by the need of pastoralists for mobility to cope with climate (rainfall) variability. Research on pastoralists has repeatedly disputed the applicability of "Secure tenure and clear territorial" boundaries (one of Ostrom's principles) to pastoralist governance systems (Moritz et al., 2013; Robinson et al., 2017). It has been suggested that traditional pastoral systems are successful due to the emphasize of their norms and institutions on flexibility and access to resources rather than secure ownership and clearly defined boundaries (Robinson and Berkes, 2010). Results of our study confirm this latest statement.

Table 3 further shows that reaching good governance under rangelands with combined private and collective grazing is possible if we consider enhancing many organizational attributes, with GDA performances remaining central. It is important to remind that devolution of natural resources management through establishment of GDA is not a final goal. The effectiveness and sustainability of resources management through empowerment of these local farmers organization remains highly important, which is not always the case in our study area (IFAD, 2018). This also confirms that local communities have the capacity to avoid the tragedy of the commons through the formation of institutions that are collectively established (Ostrom, 1990) and well performing. In

[8] Programme de développement agro-pastoral et des initiatives locales dans le Sud-Est:"The agro-pastoral development and promotion of local initiatives program for the southeast", is a local and inclusive community development program, with the effective participation of the communities concerned. The second phase of the program 2012–2020 follows a first phase initiated during the period 2003–2010.

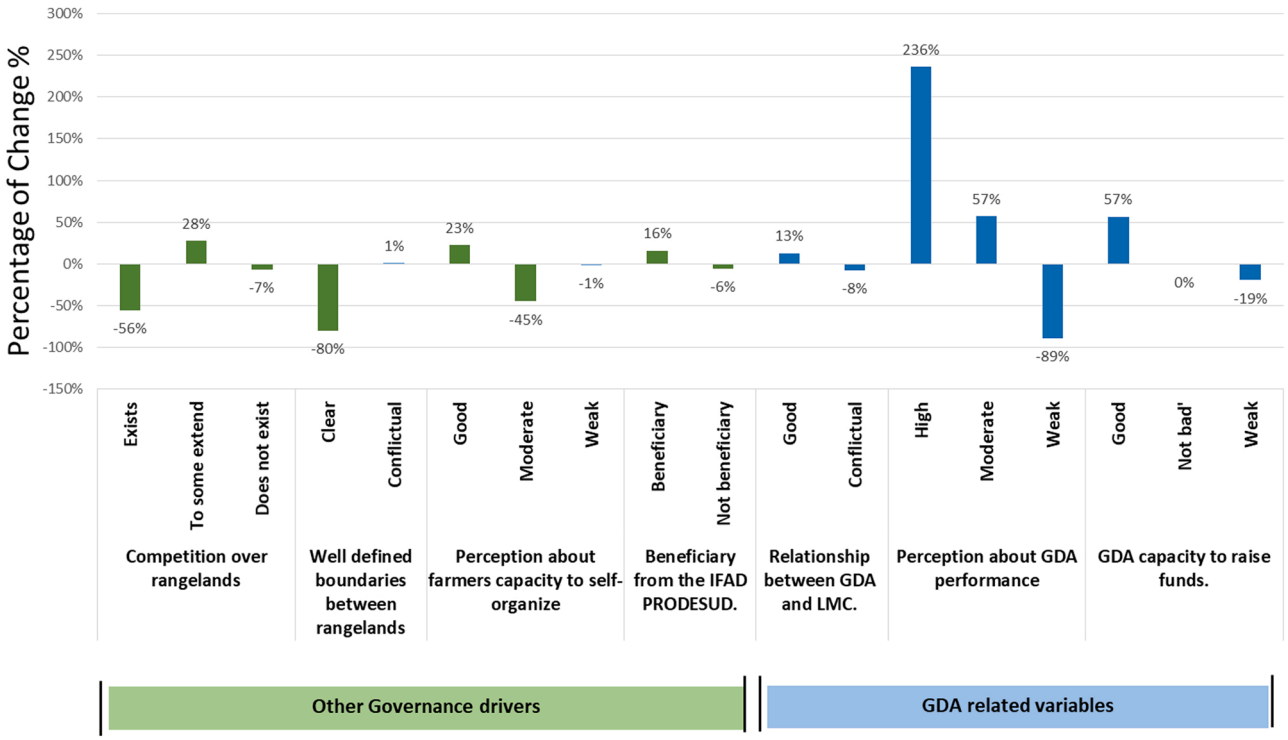

Fig. 9. Changes of conditional probabilities of the most relevant governance enabling variables under conditions of combined access to both private and collective land tenure (scenario 2 in Table 2).
Source: Own elaboration.

depth investigations of these GDA performances and identification of potential benchmarks would be needed to design capacity development programs for these key organizations.

Under exclusive private and collective land tenure systems, it is suggested that there is a need to enhance income generating activities by creating further usages of rangelands in addition to grazing. In fact, many pastoral groups have diversified their agricultural activities to different cropping systems and other forms of livelihoods, thus raising contentious questions about appropriate land uses, rangeland conservation goals, and the ability of land tenure systems to manage new livelihoods opportunities and land use transitions (McCabe et al., 2010; Rignall and Kusunose, 2018). This has been confirmed in other contexts

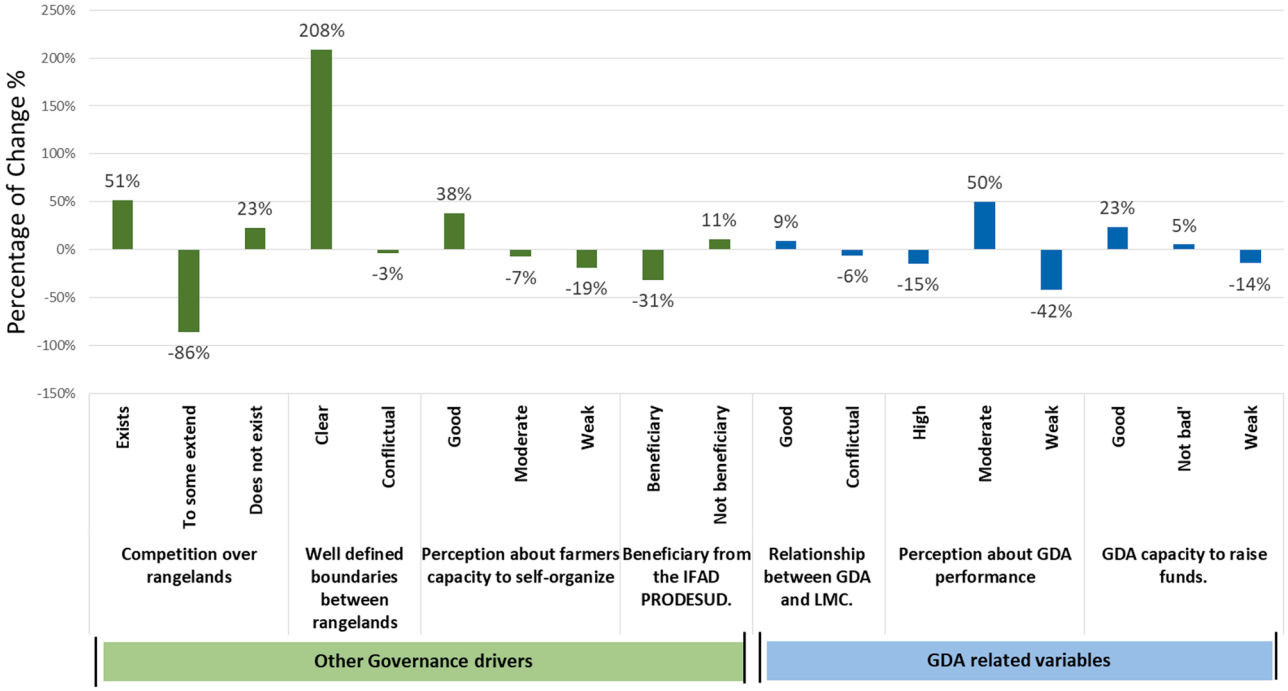

Fig. 10. Changes of conditional probabilities of the most relevant governance enabling variables under collective land tenure systems (scenario 3, Table 2).
Source: Own elaboration.

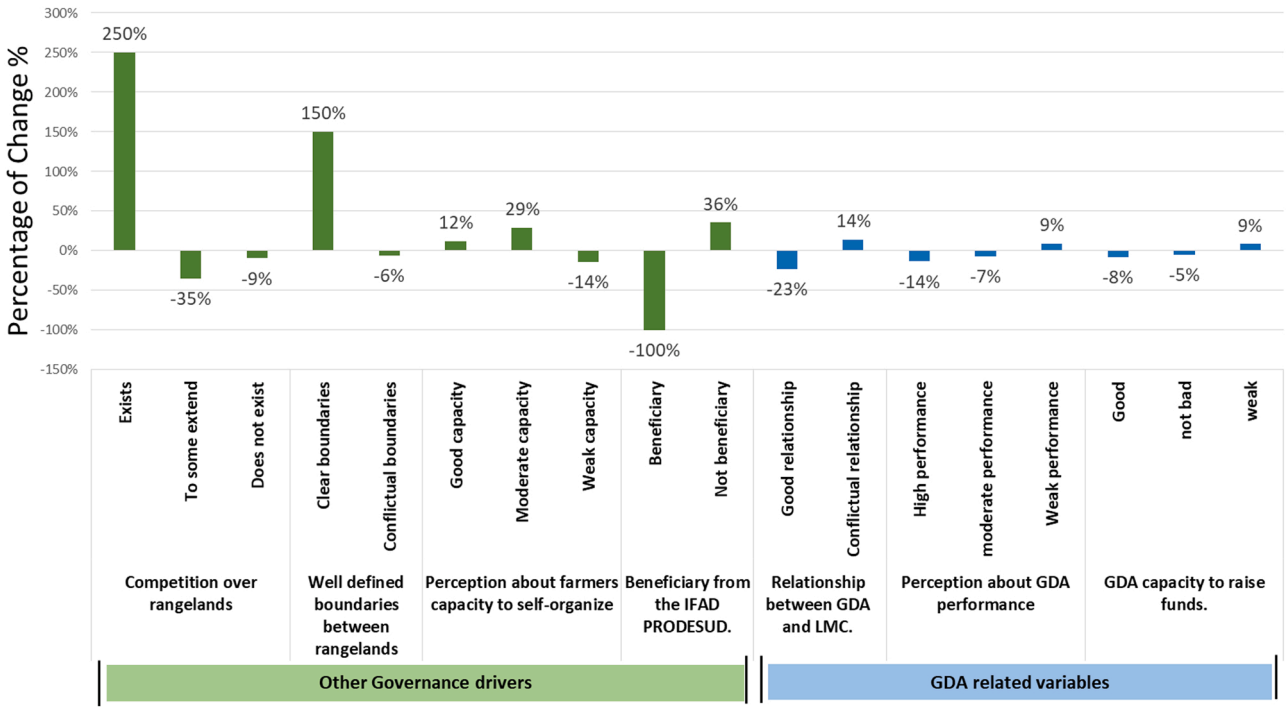

Fig. 11. Changes of conditional probabilities of the most relevant governance enabling variables under private land tenure systems (scenario 4 in Table 2). Source: Own elaboration.

such us Tanzania (McCabe et al., 2010) and Morocco (Rignall and Kusunose, 2018). In South Tunisia, pastoralists are slowly shifting to other diversified forms of livelihood, such as cultivation and wage labor, while keeping their livestock herds as part of their main assets (but involving a change in the way livestock herds are managed and fed) (Nefzaoui and Salem, 2011). The need for diversification also demonstrates that diversification of rangeland use allows agro-pastoral farmers to be in a better position (less financial pressure) for properly manage and govern their rangelands in a more sustainable way. This mutual constitutive relationship of the new economic and social realities setting new demands on land (Rignall and Kusunose, 2018), with new land uses offering new opportunities and constraining rangeland governance, is one of the most relevant findings of this paper. This also shows that rangeland restoration programs and investments need to be embedded into broader perspectives of economic and territorial development of pastoral areas.

It was also shown that infrastructural and other forms of "pastoral investments" in rangelands communities is not always a driver of good rangeland governance (case of PRODESUD investments in the study area). A relationship do exist between land tenure systems, land rights and investments (Bambio and Bouayad Agha, 2018; Fenske, 2011; Lawry et al., 2014). However, this relationship is complex and is depending on many factors including initial land rights in place, and the socioeconomic conditions of the local communities (Deininger et al., 2008). This paper provides the evidence that development of rangeland infrastructural investments is not always a positive driver of good rangeland governance, and that their respective effect will depend on the land tenure systems and the capacity of local organizations to implement and make good use of these investments to enhance its service provision.

5. Conclusion

This paper aims at identifying potential options for enhancing rangeland governance under diverse land tenure systems. We start from the hypothesis that enabling factors for good rangeland governance are different from one tenure system to another. We found out that several organizational and development actions can help sustaining rangeland governance in the studied context. First, empowerment of local organizations is necessary to consider in any future public investments in pastoral development and rangeland governance. Second, public pastoral policies and investments need to be different across areas of different land tenure types, thus considering local specific economic and social realities, which need to be considered. It is also important to stress that livelihood diversification was identified as a prerequisite of good governance, especially under exclusive private and collective land tenure systems. However, as suggested by Hecht, (2010), livelihood diversification can result in both disinvestment from and higher investments in agriculture, which can release some of the pressure on the resources allowing for rangeland regeneration or drive further degradation related to land use changes. While these social livelihood dynamics remain a reality, policy makers should better plan diversification of livelihood in an integrated way by rather making them highly embedded into broader pastoral territory development programs and investments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2022.106519.

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