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Can local policy options reverse the decline process of small and marginalized rural areas influenced by global change?

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ABSTRACT

Rural depopulation generates deep territorial imbalances, threats regional food security, and causes the irreversible loss of culture and local institutions that manage natural resources and ecosystem services worldwide. While local leadership and economic diversification have been pointed as factors that could trigger rural development, what happens to remote rural areas whose continuous process of depopulation has undermined their social capital and leadership and their endogenous capacity for economic diversification? What realistic policy options could trigger an effective and endogenous rural development process in these weakened areas? Here we used a dynamic simulation model and a sensitivity analysis to explore the long-term effects of local policy options suggested by institutional, academic and local stakeholders that could act on leverage points to revert the depopulation of a marginalized rural area in Mexico, the oasis of Comondú in Baja California Sur. The identified leverage points are related to improving the production yields of irrigated agriculture and livestock farming, the main economic activities of this social-ecological system. Our results showed the positive, but limited, effects of acting on these leverage points. However, they seem plausible good places to act to start an endogenous revitalization process in this rural area. We found complementariness between the stakeholders' management proposals, and high proximity of these proposals to the leverage points, especially the most place-based-specific proposals. This study shows the relevance of place-based research for rural development and how modeling is a valuable decision support tool to evaluate in advance the effectiveness of policy options proposed by stakeholders.

1. Introduction

Rural depopulation is a worldwide process that produces territorial imbalances, increasing the gap between rural and urban areas (Camarero and Oliva, 2019). It is considered a natural process linked to industrialization, but its negative effects are commonly maintained and exacerbated long after the industrialization has taken place (del Pino and Camarero, 2017). Depopulation traps rural areas in a disadvantaged position in comparison with urban areas, with a weakened social capital, poor access to public services, and ageing and masculinized populations, which makes difficult for rural populations to escape from the vicious circle of depopulation (European Commission, 2008; Camarero and Oliva, 2019). The disappearance of rural populations could be trivial for many or even desirable if we think that this is a "natural process", which it is not necessary to stop, and even could bring beneficial effects not only to poverty alleviation but even to recover and preserve natural areas (Grau and Aide, 2007). However, this point of view has been controversial for its simplicity (Robson and Nayak, 2010; Defries et al.,

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2010). The decline of rural populations has major implications beyond demographic changes and territorial imbalances. It threats regional food security under the uncertainty of global change (Li et al., 2016, 2019), and carries with it the irreversible and invaluable loss of culture, traditional ecological knowledge, and local institutions that manage natural resources and ecosystem services (Robson and Berkes, 2011; Gretter et al., 2018; Sõukand and Pieroni, 2019). Rural development and the improvement of living conditions in remote rural areas is now more necessary than ever.

In the literature, we can find opposite arguments about the role of development aid on migration. Some authors postulate these aids do not halt migration but rather accentuates it by increasing people's capabilities and aspirations (de Haas, 2007). However, recent studies evidence the relevance of contextual factors, and the differential effects of development aid between urban and rural areas (Gamso and Yuldashev, 2018). In this sense, rural development has been proposed as an effective strategy to halt rural-urban out-migration processes as it diminishes regional polarization and inequality between rural and urban areas, and even reduces international migration, thanks to its positive impacts on rural labor markets (Gamso and Yuldashev, 2018; FAO, 2018). In addition, rural development interventions contribute to meet our global 2030 Agenda for Sustainable Development and the Sustainable Development Goals (International Fund for Agricultural Development IFAD, 2019), especially the SDG1 ("No poverty") and the SDG 2 ("Zero hunger"), highlighting the importance of local action implementation to scale up the effects on higher scales (from local to global).

Local leadership, social capital, and the diversification of local economies have been pointed out as relevant factors for rural development processes (Li et al., 2016, 2019). However, out-migration is a selective process, and frequently the younger, innovative, and active people leave first rural areas (Camarero and Oliva, 2019). Thus, what happens to remote rural areas whose continuous process of depopulation has undermined their social capital and leadership and their endogenous capacity for economic diversification? What realistic policy options could trigger an effective and endogenous rural development process in these weakened areas? Here we explore these questions assessing the long-term effects of local policy options suggested by institutional, academic and local stakeholders that could act as leverage points to revert the depopulation of a marginalized rural area in Mexico, the oasis of Comondú in Baja California Sur.

The oasis of Comondú has undergone a dramatic out-migration process in the past century, influenced by poor local conditions and environmental and socio-economic changes on global and regional scales (Tenza et al., 2017, 2019). Consequently, the local institutions that manage natural resources, and maintain local practices as well as local and traditional ecological knowledge, are disappearing (Cariño et al., 2013; Tenza et al., 2017). In previous research (Tenza et al., 2019), we successfully simulated the historical behavior of this oasis over the last 70 years and analyzed the main structural causes of its decline building a dynamic simulation model called SESSMO ("Social-Ecological System Sustainability Model"). Thus, SESSMO simulates the complex relationship between the social and ecological components (Ostrom, 2009) of an agroecosystem.

We herein present an advanced step of a long-term, place-based research that use the SESSMO dynamic simulation model to identify the most sensitive places in the current system's structure or leverage points to intervene, i.e., the system's components whose slight modification can trigger qualitative changes in system dynamics with relatively little effort (Meadows, 1999; Abson et al., 2017), and to analyze their capacity to revert rural depopulation in the oasis of Comondú. We then compare the obtained results with the rural development policy options proposed by the stakeholders to analyze their level of concordance and potential efficiency. Finally, we briefly discuss the implications of these policy options in the context of rural development and the achievement of the SDGs.

2. Methods

2.1. Study system and historical dynamics

The oasis of Comondú in BCS (Mexico) is a long-lived socio-ecological system (SES) that has played an important role in the region's economy and culture (Cariño et al., 2013). Surrounded by an arid environment, the availability of water emerging from natural springs has historically supported irrigated agriculture complemented by livestock farming as their main economic and productive activities (see a map of the study area and more details in Appendix A). The oasis comprises two villages: San José de Comondú and San Miguel de Comondú.

This system has undergone a dramatic transition from growth to decline in the first half of the twentieth century when the population dropped from 1006 inhabitants in 1940–257 in 2010 (a reduction of 74.5%, Tenza et al., 2017). This depopulation process could be explained by the interplay between local factors (i.e., local employment, local economy and land distribution) and the effects of regional and global drivers (Tenza et al., 2019). High unemployment rates and poor conditions in terms of economy and services, along with a wide inequality in land distribution, in the first half of the twentieth century have acted as push factors that have triggered a marked out-migration process (Tenza et al., 2017, 2019). In combination with these local factors, regional drivers related with regional development policies have acted as pull factors by contributing to marginalization and, thus, to the oasis' depopulation: i) modernization and expansion of technical agriculture in other BCS areas; and ii) deviation of public investment to other urban areas and coastal tourism centers. In addition, the change in property rights to deliver common lands to landless people boosted the livestock activity role in the local economy of the oasis, which increased its sensitivity to global climate (i.e., rainfall variability and extreme weather events like droughts and hurricanes) and market drivers (i.e., market prices of livestock products).

2.2. Model description

SESSMO was built with quantitative and qualitative data from different sources (i.e., in-depth interviews with local inhabitants, statistical data, and expert knowledge, see more details of data collection and fieldwork in Tenza et al., 2017, 2019). The 62% of the model's parameters were defined by the data provided by the stakeholders (Tenza et al., 2019). This model simulated the historical behavior of the oasis of Comondú between 1940 and 2010 focused on five principal variables: human population, irrigated land, occupied ranches, cattle and goat herding (Tenza et al., 2017, 2019, see model description, flow diagram and main simulation results in Appendix A). The model relied on the System Dynamics approach, where the system's complexity emerges from nonlinear relationships, feedback and information or material delays. The model was developed with the Vensim DSS 6.4c software (Ventana Systems) and was successfully tested by structural and behavioral tests (Barlas, 1996) by Tenza et al. (2019).

2.3. Local sensitivity analysis and leverage points for change

A local sensitivity analysis consists in modifying the value of one of the model's parameters at a given time to analyze the response on the behavior of the target variables. In a System Dynamics approach, sensitivity analyses are commonly used to assess a model's robustness (Barlas, 1996). Nevertheless, they have also proven useful for improving model formulation (i.e., removing the least sensitive parameters), identifying leverage points (i.e., parameters to whose changes the model is more responsive), and quantifying uncertainty in the assessment of policies (Banos-González et al., 2018). Leverage points, which can range from changes in parameters to changes in paradigms, feedback or time delays, are the best places to intervene in a system by policies or management measures (Meadows, 1999; Abson et al., 2017). Here we used a local sensitivity analysis to identify SESSMO's most sensitive parameters, which are potentially manageable by rural development policies (for more details about the sensitivity analysis and how to calculate the sensitivity index for each parameter see Appendix B).

From the list of sensitive parameters identified by the local sensitivity analysis (Appendix B), we selected those sensitive parameters that were modifiable by rural development policies and management measures as potential leverage points: i) cattle birth rate; ii) cheese production per goat; iii) goats birth rate; iv) weight of cattle for sale; v) yield of irrigated land. Thus, the parameters with low sensitivity (e.g., cattle per labor unit) and those not modifiable (e.g., average rainfall) were excluded from the analysis.

2.4. Rural development scenarios

The rural development scenarios that focused on intervening on the leverage points were grouped into the three main productive sectors of the study area: i) improved agricultural yield; ii) improved cattle yields; iii) improved goat yields. We defined the level of improvement over these leverage points according to the realistic changes made in similar productive systems with technical assistance and technological packages (Table 1). Improving livestock yield (goats and cattle) would give rise to increases in the model values from 6.5% to 35%, which is feasible with technical assistance and technology packages that focus on livestock health, livestock management and reproduction-genetics issues (Cepeda and Angulo, 2013). Enhancing agriculture yield would mean an 80% increase in the model value, which is reasonable when considering that an extensive global assessment of agroecology demonstrated that low cost, locally available and environmentally sensitive practices, and technologies could lead to increases in yields from 50% to 100% per hectare (Pretty et al., 2003).

We simulated eight alternative scenarios for the 2010–2050 period, including the "business-as-usual scenario" (*BAU scenario*), which implied no changes in the parameters, three scenarios with changes in each separate economic sector (i.e., agriculture, cattle farming and goat farming), three scenarios with combinations of economic sectors in pairs, and a scenario with changes in all the economic sectors at one given time. In all the scenarios, the rural development policies and management measures were implemented starting from 2020. We decided to do this because of the time in which a policy or action is implemented matters because it affects outcomes (Pérez et al., 2012). At the time we wrote this paper, some changes had taken place in the oasis of Comondú. However, no policy or action has yet focused on these leverage points. Therefore, we discarded implementing policies early in the simulation. As mentioned before, SESSMO includes external drivers (i.e., rainfall, hurricanes, market prices) as input data, which are the time series of each driver's historical behavior. As the future regional scenarios of these drivers were lacking, we used an extension of the historical trends of external drivers by repeating historical patterns (see Appendix A for details about climate data used in the scenarios). To analyze the capacity of the leverage points selected to change the system's expected trend, we compared the simulation results of each scenario with the *BAU scenario* as a reference. Comparisons focused on the final variable *population* value obtained at the end of the simulation.

Table 1
Changes in model parameters associated with the identified leverage points.

Parameter	Model value	Improved value	Units
Yield of irrigated land	2663	4793	kg ha^{-1}
Weight of cattle for sale	250	315	kg cattle^{-1}
Cattle birth rate	0.57	0.644	year^{-1}
Cheese production per goat	21	22.4	kg goat^{-1}
Goats birth rate	1	1.35	year^{-1}

2.5. Stakeholders' management proposals

To study the convergence between the selected leverage points of SESSMO and local stakeholders' management preferences, we extensively collected the management measures proposed by the local inhabitants of the oasis, the regional BCS government and academia (i.e., researchers of the RIDISOS, "Interdisciplinary Network for Integral and Sustainable Development of the Oases of Baja California Sur"). The comparison between the simulated results and the management proposals could shed some light on what policy options are more efficient to halt depopulation and support an endogenous rural development process. Local inhabitants' preferences were collected during two 1-day participatory workshops held in San José de Comondú and San Miguel de Comondú in December 2015. During the workshops, local actors identified the oasis' main problems, defined the future desired status, and proposed management measures to move toward this future (Breceda et al., 2020). The date and time of both workshops were negotiated with local leaders to increase local inhabitants' involvement. The participants were not economically compensated for participating. Twenty-five inhabitants participated in the workshops: eight in San José de Comondú (7% of the total population), and 17 in San Miguel de Comondú (11% of the total population). The results of these workshops were presented and validated with the participants from both villages in another participatory workshop held in October 2016. In addition to workshops, we recovered some proposals from in-depth interviews that we conducted in previous fieldwork during 2010–2012 (see Tenza et al., 2017). Four key local actors of both communities described their future expectations during these interviews (i.e., three leaders of Town Councils and a relative of one of the most important merchant families in the oasis. They were all aged between 35 and 74 years and were male).

To collect the preferences of both the regional government and academia, we analyzed the strategic plans of the regional BCS government (SPyDE, 2011) and the RIDISOS publications (Tenza et al., 2011; Cariño et al., 2013; Gámez, 2013). We reviewed these documents and extracted all the management proposals. The regional government's plans were based on the strategic project for the sustainable development of the oases in BCS for the 2011–2015 period. This project was designed to enhance the living conditions of eight oases in BCS (including the oasis of Comondú) by paying attention to the productive vocation of these sites according to sustainability principles. This is a long list of actions to perform in the short, mid, and long terms, which are divided into environmental, social, economic and institutional topics. RIDISOS publications include mainly two books that focus on the oasis of Comondú (Cariño et al., 2013; Gámez, 2013). Cariño et al. (2013) is a multidisciplinary diagnosis of the current status with a detailed description of the missional past (Cariño et al., 2013). Gámez (2013) offers alternative options for developing this oasis.

Ordering the proposals into management measures and categories allowed us to compare the priorities made between local actors and the proximity or distance of such measures to the system's leverage points. To compare preferences among the identified leverage points and priorities between categories, we used the Pearson's chi-squared (χ^2) test to compare the results of each group of stakeholders in pairs.

3. Results

3.1. Simulation results of scenarios

Fig. 1 shows the behavior of the target variable *population* in the management scenarios based on leverage points. In the BAU scenario, *population* declined by 22.4% during the simulation period. The simulation began with a sharp population decline, followed by two smoother declines, and a slight recovery at the end. This behavior was explained mainly by livestock farming dynamics (Fig. 2a), and rainfall variability (i.e., rainfall and hurricanes, Appendix A) as such activity represents the study system's main economic activity, which was strongly influenced

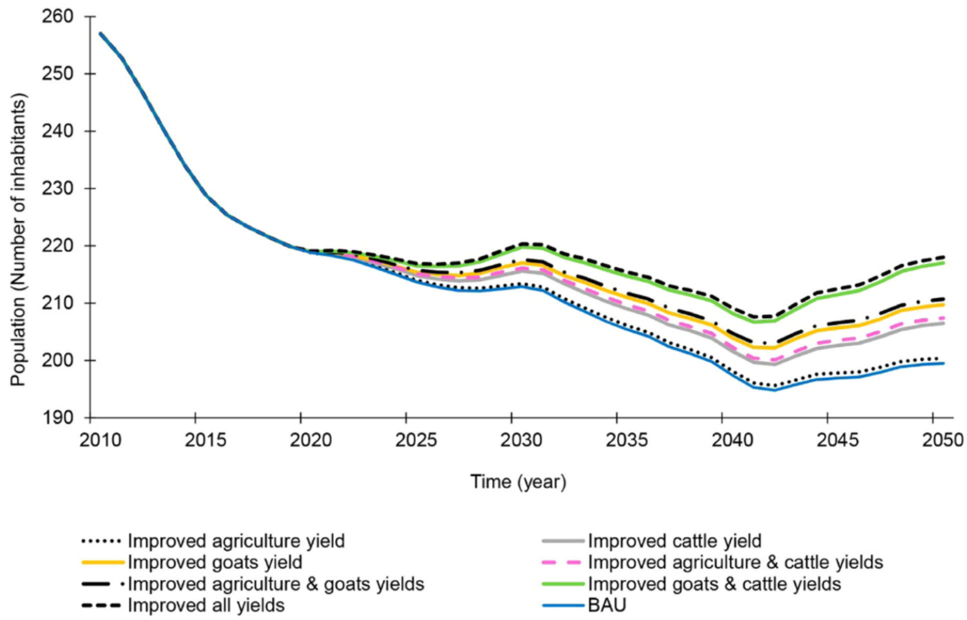

Fig. 1. Simulation results of the management scenarios on the variable *population*. Management measures were implemented starting from 2020.

by climate conditions. In the first two decades, some severe droughts profoundly affected livestock farming dynamics as cattle and goat herding reduced. Besides, several hurricanes also impacted livestock farming halfway through the simulation period by reducing livestock stocks due to their increased mortality.

Table 2 shows the variation coefficients of the alternative management scenarios concerning the BAU scenario. Improved agriculture and livestock yields slightly enhanced the local conditions by decelerating the depopulation process in some scenarios and even reversing depopulation at the simulation end time (Fig. 1). Improved goats yield was the scenario that influenced the system dynamics the most, followed by improved cattle yield (Table 2, Fig. 1). Improved agriculture yield had the least impact (Table 2, Fig. 1). In pairs, improved livestock yield (goats and cattle together) had the most substantial impact as the population was 8.8% higher than in the BAU scenario (Table 2, Fig. 1). The best result was obtained by the improvement in all the productive sectors (agriculture and livestock together) as the population was 9.3% higher than in the BAU scenario. In this scenario, *population* declined 15.2% during the simulation period, but this trend was slightly reversed in the last decade of the simulation, with a 5% increase in *population* (Table 2, Fig. 1).

Fig. 2a and b show the effects of improving the yields of livestock farming and agriculture, respectively. Enhancing the birth rate of goats and cows increased both livestock stocks, but also reduced the recovery time after external shocks like droughts or hurricanes, especially on goat herding (Fig. 2a). Enhancing agriculture yield increased total agricultural production, but did not entail the recovery of irrigated land, and the abandonment of irrigated land continued during the whole simulation period (Fig. 2b). According to the system's structure (see diagram flow in Appendix A), the total production of both activities (i.e., agriculture and livestock farming) affected the local economy which, in turn, impacted available local services. Size of livestock stocks and hectares of productive irrigated land determined the local employment demand. These two elements are critical as they act as pull or push factors on the migration flow of *population*.

3.2. Analysis of the measures proposed by stakeholders

We collected 111 proposals (see the complete list in Appendix C), which were grouped according to affinity into 22 general policy options and classified into the following categories: i) agriculture; ii) livestock farming; iii) environmental conservation; iv) land tenure; v) services and infrastructure; vi) tourism.

Table 3 shows the management measures that groups all the proposals made by stakeholders (see the complete list of proposals in Appendix C). Of the 111 proposals, 54% refer to management measures that can directly or indirectly act on the identified leverage points (Table 3). Some proposals clearly impact productive yields like investments in infrastructure and equipment for agriculture and livestock farming. Nevertheless, we consider that other proposals that center on land tenure issues, access to credits, or managing natural resources could also positively affect productive yields.

Local inhabitants and academia were the stakeholder groups that proposed more management measures, which matches the leverage points (54% and 73%, respectively, Table 3 and Fig. 3a). The regional BCS government concentrated only 35% of its measures on increasing production yields (Table 3 and Fig. 3a). The improvement of goat yields is the leverage point most supported by the local inhabitants and the academia, while the regional government focused most on agricultural yield (Fig. 3a). However, both the local inhabitants and the regional government concentrated most of their proposals on other aspects not linked to the leverage points (Fig. 3a). The comparison of the groups of actors' preferences in relation to the leverage points showed no significant differences between the proposals of the local inhabitants with the regional BCS government nor the academia (p-value > 0.05), while the academia's proposals significantly differed from those of the regional BCS government (p-value < 0.01).

Regarding the categories of the proposals, the 46% focus on enhancing traditional activities (i.e., agriculture and livestock farming), the 28% on increasing local services and infrastructure, the 13% on environmental conservation, the 10% on developing tourism as a new potential economic sector, and the 4% on solving land tenure issues (Fig. 3b). More similarity was clearly found between the proposals of the local inhabitants and the academia. They concentrated more proposals on agriculture and livestock farming, followed by the need to increase available services and infrastructure in local communities, and to diversify the economy through tourism (Fig. 3b). However, a slight difference appeared in the last two categories because academia placed more relative weight on developing tourism than developing services (including subsidies, Fig. 3b). The regional government prioritized investments in public services and infrastructures, and environmental conservation (Fig. 3b). The comparison of these groups of actors'

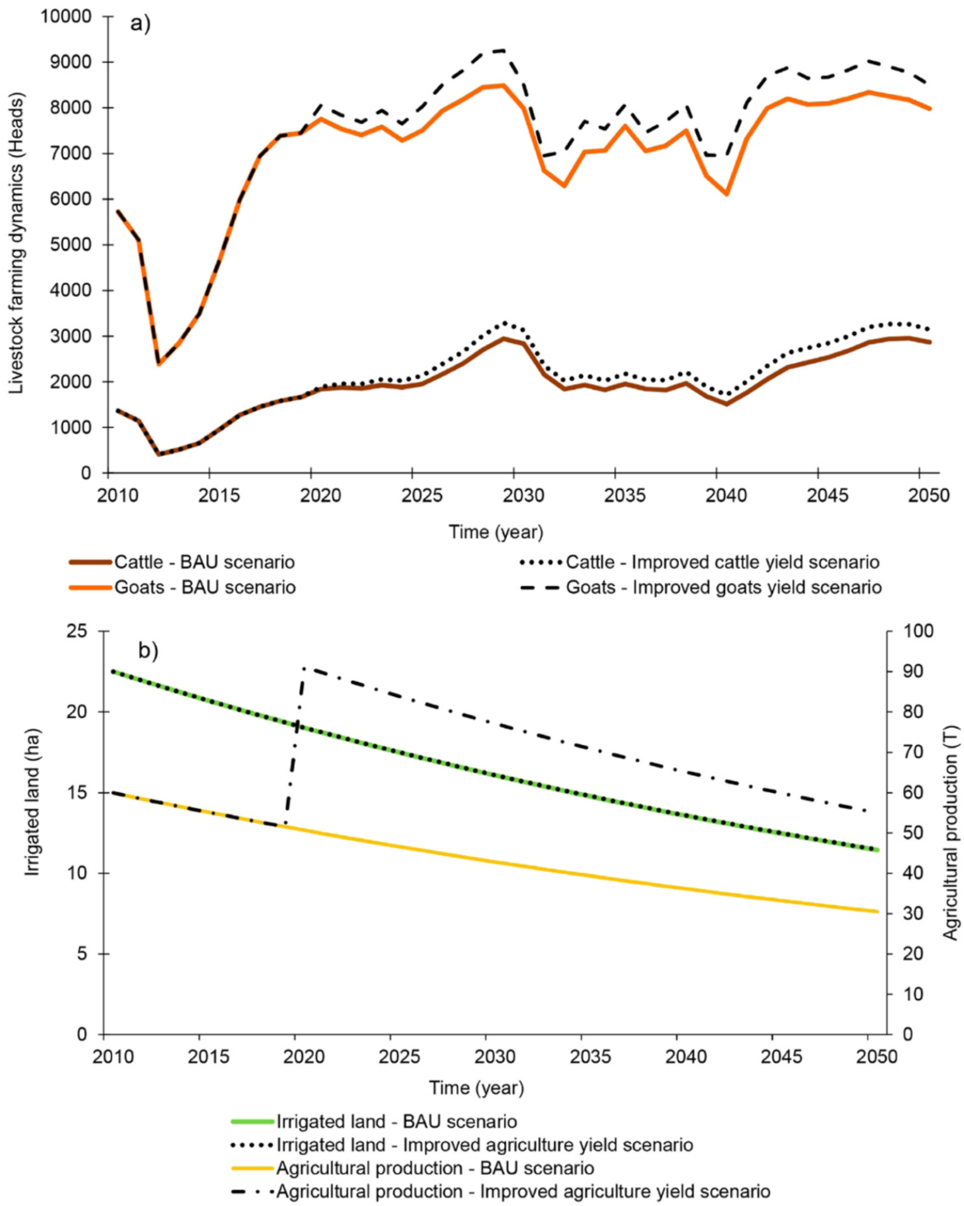

Fig. 2. Simulation results of the management scenarios on productive activities: (a) livestock farming system; (b) agriculture. Management measures were implemented starting from 2020.

Table 2
Variation coefficients of the scenarios expressed as percentages. To compare between the alternative management scenarios and the business-as-usual scenario (BAU-Scenario), we focused on the *population* value at the simulation end time (t = 2050) because it is a stock variable (i.e., a cumulative variable).

Scenario	Variation coefficient for *population* (%)
Improved agriculture yield	0.5
Improved cattle yield	3.5
Improved goats yield	5.1
Improved agriculture and cattle yields	4.0
Improved agriculture and goats yields	5.6
Improved livestock yields	8.8
Improved agriculture and livestock yields	9.3

proposals by categories showed that there were no significant differences between the proposals of them both (local inhabitants and the academia) (p-value > 0.05). The regional BCS government's proposals significantly differed from those of the local population (p-value < 0.01) and academia (p-value < 0.001).

4. Discussion and conclusions

Here we present an advanced step of a long-term place-based research to identify the potential leverage points that can be moved with realistic local policy options to halt the out-migration process in a marginalized and weakened rural area of Mexico, namely the oasis of Comondú in BCS, which has been influenced by global changes (Tenza et al., 2019). We explored the effects of these leverage points on local dynamics and their convergence with the management proposals suggested by three stakeholder groups (local inhabitants, regional government, and academia). Our results showed the positive, but limited, effects of acting on these leverage points with plausible local policy options, the proximity of the stakeholders' management proposals to these sensitive points, especially the most place-based-specific proposals, and the visible complementariness between the stakeholders' initiatives.

Table 3
Number of rural development policy options proposed by stakeholders related to the identified leverage points (AY = agricultural yields, CY = cattle yields, GY = goats yields, N = none). The proposals were grouped into categories. Asterisks ("*") indicate the potential indirect relation to the identified leverage points. Each proposal can influence more than one leverage point. Some proposals are not related to them (i.e., None). The complete and detailed list of proposals can be consulted in Appendix C.

Group of stakeholders		Local inhabitants				Government of BCS				Academia			
Category	General rural development policy options	AY	CY	GY	N	AY	CY	GY	N	AY	CY	GY	N
Agriculture	Access to credits*									1			
	Diversification of agricultural products									2			
	Investments in infrastructure and agricultural equipment					1							
	Irrigation system recovery	4			2	1							
	New marketing schemes for agricultural products*				1				1				3
	Reactivation of agricultural activity	2								2			
Environmental conservation	Conserving ecosystems and biological diversity*								3	1			
	Managing natural resources*		2	2		1			5				
	Preventing wildfires*				1				1				
Land tenure	Solving land tenure issues*	2	2	2		1	1	1		1	1	1	
Livestock farming	Complementariness between agricultural and livestock activities (fodder crops and manure)									2	2	2	
	Diversification of livestock products		1	2							1	1	
	Genetic improvement of livestock by hybridization		2	1							1	1	
	Infrastructure for water collection and storage						1	1			2	2	
	Investment in infrastructure and livestock equipment				1		1	1			2	4	
	Creating a local cooperative for livestock farming*			1	1								1
	New marketing schemes for livestock products*				4				1				2
	Partial-stabled livestock herds			1							3	3	
Services and infrastructure	Investments in public services*	1	1	1	4	4	3	3	10	1	1	1	2
	Subsidies*	2	2	2	1	3	2	2	1	1	2	2	
Tourism	Selling of handicrafts*	1	1	1					1	1	1	1	
	Developing tourism*				2				1	3	3	3	2
Total		12	11	13	17	11	8	8	24	15	19	21	10

4.1. Acting on the leverage points

Dynamic simulation models and sensitivity analyses are useful decision-support tools to develop more effective management measures as they embrace the complexity and uncertainty that are inherent to SESs (Perz et al., 2013; Banos-González et al., 2018). Of the 28 analyzed parameters (see Appendix B for a complete list), five were identified as leverage points (i.e., sensitive parameters potentially modifiable by rural development policies): i) cattle birth rate; ii) cheese production per goat; iii) goats birth rate; iv) weight of cattle for sale; v) yield of irrigated land. The management scenarios that focused on intervening on leverage points were grouped into: i) improved agricultural yield; ii) improved cattle yields; iii) improved goat yields. The results of this study indicated that improvement in livestock yields had the strongest impact because of its positive effects on both the local economy and local employment demand, which could halt the out-migration process. The depopulation process decelerated, and the population in the last simulation decade slightly increased. Enhanced agriculture production had a lesser effect. One possible reason for this would be that agricultural yields would not be enough to reactivate abandoned irrigated land and to increase local employment demand. However, the best quantitative results were obtained by jointly improving agriculture and livestock yields.

So, the herein examined leverage points are sensitive but not miraculous places. Our results evidence that although realistic improvements in livestock farming yields (Cepeda and Angulo, 2013) and agriculture yields (Pretty et al., 2003) are accessible parameters to be modified, such changes would only slightly improve local conditions in the short and mid-terms, and probably would not suffice to reverse the current decline process sustainably, but they seem plausible good places to act in the first place to start an endogenous revitalization process in the oasis. In future research steps, we will analyze the effects of not only complementary measures that focus on traditional productive sectors (e.g., add value to agriculture and livestock products), but also of management measures that imply making changes in the systeḿs structure (e.g., developing a new economic sector like tourism), which were also proposed by the stakeholders and could have a stronger repercussion on local dynamics.

Apart from leverage points' limited effects, they could engender trade-offs with environmental and socio-economic uncertainty (Meadows, 1999; Anderies et al., 2007; Abson et al., 2017). Although increasing livestock and agriculture yields can improve the local economy and increase both local services and local employment demand when external factors like climate and market prices are favorable, they could make the system more sensitive to climate or socio-economic disturbances. Our analysis highlights that livestock activity is the best place to intervene but is extremely vulnerable to droughts and hurricanes. Those extreme weather events have been historically frequent in the study area and might be exacerbated in the future due to climate change (Tenza et al., 2019). As Anderies et al. (2007) suggested, increasing the SES' robustness to certain disturbances is paid by gaining sensitivity to other elements of uncertainty. Learning and adaptive management are needed to deal with uncertainty. Thus, management measures that focus on increasing the production yields of livestock activity should be accompanied by others that directly enhance the livestock farming system's adaptive capacity to climate variability.

Despite the importance of these conclusions for system development, we need to highlight some of our model's limitations that may overestimate the effects of the examined leverage points. For example, SESSMO neither includes stochastic behaviors, which might affect livestock dynamics, nor separates the human population into age groups, which may restrain the recovery of this SES due to ageing effects. We analyzed the management scenarios only with one future scenario of external drivers (i.e., rainfall, hurricanes, and market prices), which extends the historical trends of these drivers. Future analyses should include an extensive array of possible future scenarios, including climate change scenarios for this region. Moreover, SESSMO assumes that increased production yields would be accompanied by the sale of all products. In the real world, the measures directed to increase production yields should be complemented with measures that ensure access to suitable markets and an increase in the demand of these products and should also enhance and strengthen social capital.

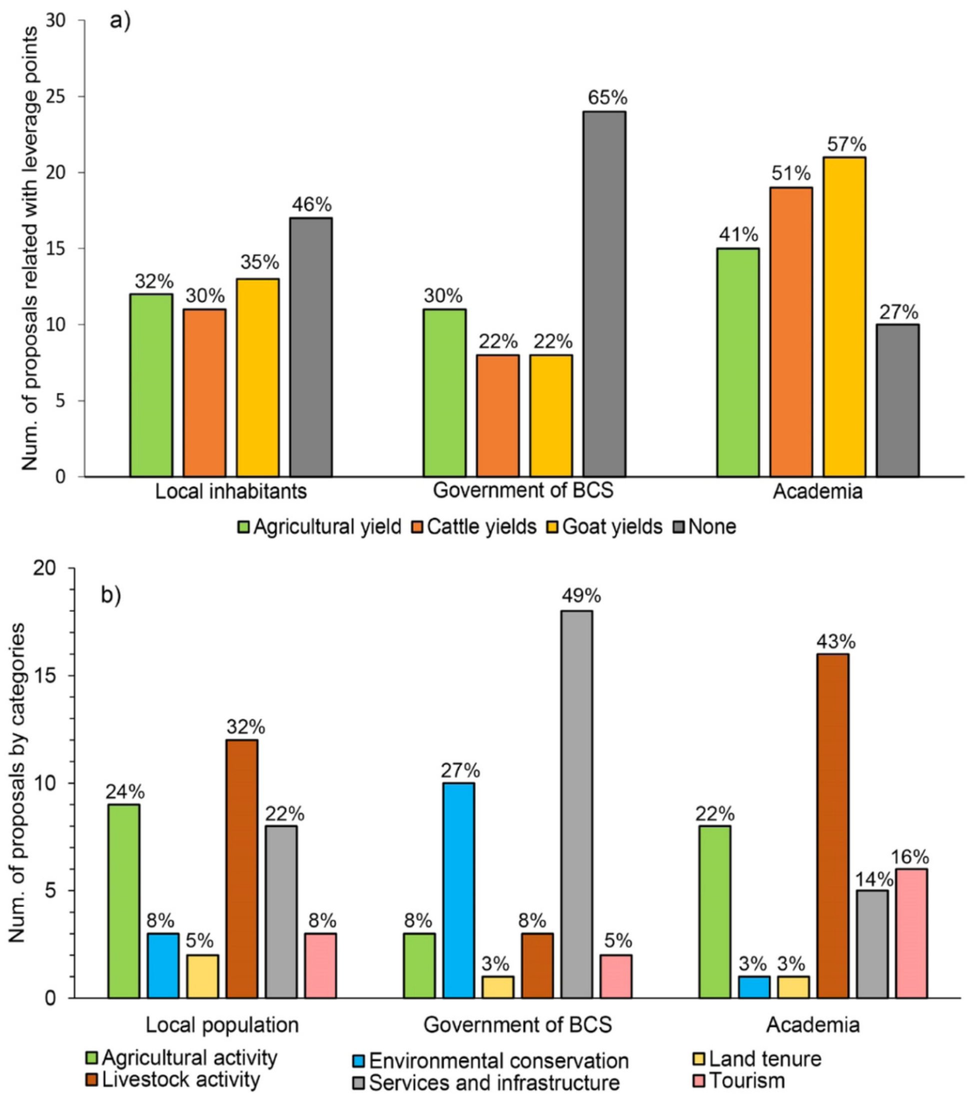

Fig. 3. Comparison of the management measures proposed by stakeholders: (a) grouped by their relationship with the leverage points and (b) grouped by categories.

4.2. Comparing stakeholders' proposals and their implications to rural development

Local inhabitants and academia showed more convergence and proximity to leverage points, being the improvement of goat yields the most supported by their management proposals. This result agrees with simulation results that identified goat herding as the most reactive productive sector. This is not a surprising result because, as Meadows (1999) pointed out, stakeholders usually have an intuition about where leverage points are located in a system. The improvement of agricultural yield was supported by all the group of actors, but especially by the regional BCS government. Our simulation results revealed the limited effects of increasing the agricultural yield under the current situation where there is less than 25 ha in production. Possibly, this improvement should be accompanied by other measures like new marketing schemes (e.g., add value to local products, new market channels into organics) to be more effective. The traditional agricultural activity in the oasis has deep roots into the imaginary of the local population. This activity has linked with the greatness of this rural area, its golden age (Tenza et al., 2017). This romantic view percolated profoundly in the academia and was reflected in the associated publications (Cariño et al., 2013), which has potentially influenced the regional BCS government development programs with management measures focused on the recovery of irrigation systems in the oases. Recent studies challenged this view (Tenza et al., 2019), highlighting the role of endogenous conditions (i.e., high unemployment, poor economy, and even inequality in land distribution) and dependence on livestock farming and its vulnerability to climate variability as major drivers of change in this rural area. However, the recovery of the agriculture and its interrelation with livestock farming, which involve to build and reinforce a feedback relationship between both activities (e.g., provision of manure to agriculture, production of forage for feeding animals in times of scarcity), could have positive and interesting effects to analyze on the oasis, strengthening the resilience of this rural area to climate variability.

Local inhabitants and academia also focused most of their proposals on traditional agriculture and livestock farming activities, while the regional government's proposals focused mainly on providing public services and environmental conservation. To understand the dissimilarities among actors, we also need to take into account the different scale on which each group's proposals is oriented. Both academia and local actors focused their proposals on the local scale, while government proposals arose from a regional scale to respond to the general development problems of the oases in BCS. This explains, for example, why local inhabitants and academy did not focus their proposals on environmental conservation, while the government concentrated almost 30% of them on this objective. Unlike other oases of BCS (e.g., San José del Cabo), the oasis of Comondú has a good environmental conservation status to date, with 30.5% of its vertebrate fauna listed in some protection category in NOM-059-SEMARNAT-2010, and 13.5% as endemisms (Pérez-García et al., 2013).

The different stakeholders' proposals are clearly complementary, and all together they have more possibilities to effectively contribute to rural development and meet the SDGs at local and regional scales (see Appendix D). The management proposals are coherent with the objectives of the Mexican Sustainable Rural Development Law and can contribute to increase socio-economic well-being and to correct regional development disparities (see Appendix D). In addition, these proposals have the potential to contribute to 13 out of 17 SDGs, especially to the SDG 8 ("Decent work and economic growth"), SDG 2 ("Zero hunger"), SDG 9 ("Industry, innovation and infrastructure"), and SDG 11 ("Sustainable cities and communities", see Appendix D). In this context, a window of opportunity opens to support the management proposals of the stakeholders and contribute to the rural development of the oases of BCS as the regional government has been strongly committed to the Agenda 2030 since 2018. Notwithstanding, bonding (internal) and bridging (external) social capital in local communities are key aspects of rural development (Li et al., 2019). Depopulated rural areas usually have an eroded social capital, which results in individualistic behavior and mistrust among local community members which, in turn, hinders rural development (Li et al., 2019). This is one of the most important challenges in our case study. In this sense, part of the effort made by all stakeholders, even possible NGOs, should be directed to build social capital, leadership and organization in local communities to underpin rural development, and to strengthen the SES's resilience and adaptive capacity.

It should be notice that the increased support from the regional government to the oases of BCS in the last decade, starts to show good results. In the oasis of Comondú, some returned migrants, with a high level of education and economic resources, have started their businesses linked to local tourism in the last years. However, the last population census shows worryingly that the population has decreased by 20% compared to the value of 2010 (from 257 inhabitants to 205). The emerging economic revitalization should be also accompanied by the regional government with funding, training and technical assistance to empower residents to diversify and improve the local economy, which may also increase the number of returnees. The improvements analyzed here are feasible, and with appropriate technical (and veterinary) assistance, could be the initial leverage points needed.

Planning rural development policies is a challenging task due to the wide diversity of problems of rural areas and the context variables that can influence outcomes (e.g., values, culture, social networks, demographics). This study shows the relevance of place-based research for rural development and how SES modeling is a valuable decision support tool to evaluate in advance the effectiveness and robustness of rural development policies or management measures proposed by stakeholders. This methodological approach can be applied to other rural areas in the world.

CRediT authorship contribution statement

Alicia Tenza-Peral: Conceptualization, Methodology, Investigation, Formal Analysis, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Irene Pérez-Ibarra:** Investigation, Writing – original draft, Writing – review & editing, Visualization. **Aurora Breceda:** Methodology, Writing – review & editing, Funding acquisition, Project administration. **Julia Martínez-Fernández:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Andrés Giménez:** Conceptualization, Investigation, Writing – review & editing, Supervision.

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.

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Appendices Supporting information (Appendix A, B, C, and D)

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.10.007.

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