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Mediterranean goat production systems: vulnerability to population growth and climate change

Olivia Florence Godber and Richard Wall

University of Bristol, United Kingdom

Abstract: In many Mediterranean countries, particularly those with substantive areas of marginal habitat that is unsuitable for crop production, small ruminant husbandry, especially goat production, is an important contributor to the national economy, rural livelihood and food security. In this study, the vulnerability of goat production in the Mediterranean region is modelled using vulnerability analysis, to consider the effects of changes in climate, human population and novel disease. A range of indicators derived from FAOSTAT and World Bank statistics are used. The model shows that southern Mediterranean nations are the most vulnerable, while Greece is the most vulnerable nation of the European Union (vulnerability score of 0.47 on a scale of zero to one, ranked seventh overall). The relatively higher adaptive capacity of France, Italy and Spain (scores of 1.00, 0.84 and 0.77 respectively on a scale of zero to one) is shown to counteract their high exposure (scores of 0.89, 0.91 and 0.96 for France, Spain and Italy respectively on a scale of zero to one) and reduce overall vulnerability (scores of 0.0, 0.05 and 0.13 for France, Spain and Italy respectively on a scale of zero to one). Morocco, the second most vulnerable nation of the Mediterranean with a vulnerability score of 0.81 (on a scale of zero to one), is selected to demonstrate the complexity of potential mitigating strategies and the interaction of the drivers of vulnerability.

Key words: goats; Mediterranean; food security; vulnerability; climate change.

Introduction

The sustainability of livestock husbandry is affected by a wide range of environmental challenges, not least of which is climate change [1, 2]. Along with anticipated changes in climate, intensification of production systems and the extension and growing complexity of market chains to meet product demand could also affect disease risks [3]. Marginal areas, where factors such as climate and topography make arable production impractical and hence food derived from livestock a necessity [1], are common in the Mediterranean region. However, there is little detailed analysis of the vulnerability of livestock production to environmental perturbation within these areas.

Vulnerability analysis is a modelling approach widely used in global change science and in studies of food security and economics [4-6]. This is a tool for predicting potential impacts on coupled human-environment systems that can inform and guide policy decision-making and help to target interventions [5]. Vulnerability is considered to be the product of sensitivity, exposure and adaptive capacity [5]. Sensitivity can represent the dependence on a specific driver and its importance to a sector, for instance the economy [7]. Measures of exposure attempt to capture the extent to which a

system will be influenced by any specific change and adaptive capacity the ability of a system to undertake mitigating responses. The latter typically includes information on the financial strength of government and industry, communications infrastructure and per capita affluence [8].

The aim of the work described here was to adapt a previously published broad-based global livestock vulnerability model [4]. The study focused specifically on the sensitivity, exposure and adaptive capacity of the goat husbandry sector in Mediterranean nations to the anticipated effects of climate change, population growth and novel disease. These three indices are then used to estimate the potential vulnerability of each nation and the contribution of its goat sector to food security. The interaction between the different elements which contribute to the vulnerability of Morocco are then considered in more detail to highlight the interactions between the various components.

The goat sector is the focus of this study because goat production is highly concentrated around the Mediterranean and has an important socio-economic role. There are few other agricultural economic activities possible in these regions [9]. Goats are also an important source of protein through both dairy and meat production [10], and can provide a

more varied and healthier nutritional regime for the household than a pure crop system, particularly for children [11]; this is especially true for the southern Mediterranean nations, Morocco in particular [12-14]. Previous work has identified Morocco as being highly vulnerable to climate change [15, 16], but did not focus on the livestock sector, and no other study to the authors' knowledge has looked specifically at the vulnerability of the goat sector, or the livestock sector in general.

Materials and methods

FAOSTAT and World Bank data banks were searched for suitable recent quantitative indicators

relevant to goat production, food security, climate change, population growth and socio-economic status. Sufficient data could be obtained for the year 2011, using 11 informative indicators (Table 1) for 17 nations. The indices selected to determine the sensitivity of a nation where: the percentage of a population receiving inadequate nutrition [17] as an indicator of food security; the aggregated volume of milk and meat produced per goat by a nation [17], as an indicator of how productive the national goat herd was; and the volume of home produced goat products available per capita [17], as an indicator of how important goat products currently are to the nation's diet.

Table 1. Summary of indicators used to calculate sensitivity, exposure and adaptive capacity and the source of the data.

Index	Indicator		Source	
Sensitivity – level of food security, productivity of goats and volume of home-produced goat products consumed per capita	Food insecurity	Prevalence of food inadequacy. A reflection of food availability, stability, utilisation and access.	[17]	
	Goat productivity	Volume of produce per goat (kg meat per goat + kg milk per goat).	[17]	
	Nutritional contribution	Volume of home produced goat products consumed per capita (kg meat per capita + kg milk per capita).	[17]	
Exposure - impact of projected changes in climate based on the current percentage of population affected by drought, flooding and extreme weather and projected population growth of nations in addition to risk of importing goat disease	Precipitation	Projected change in annual average precipitation (2045 - 2065)	[18]	
	Temperature	Projected change in annual average temperature (2045 - 2065)	[18]	
	Extreme weather	Population affected by droughts, flooding and extreme weather (1990 - 2009)	[18]	
	Population growth	Projected population change (2010 - 2050)	[18]	
	Disease risk	Heads of goats imported per annum.	[18]	
Adaptive capacity – nations' abilities to change in response to or cope with changes in climate, food demand and goat disease status.	Health	Life expectancy	[22]	
	Economy	Total GDP	[17]	
	Governance	Control of corruption		[22]
		Government effectiveness		[22]
		Political stability and absence of violence/terrorism		[22]
		Regulatory quality		[22]
		Rule of law		[22]
Voice and accountability		[22]		

The indices selected to determine the climate change element of exposure were based on climate

change projections for 2045 to 2065 taken from an ensemble of data from nine general circulation

models run under the IPCC A2 scenario [18]. Annual averages are given relative to the period 1961 to 2000 and aggregated to country level from 2-degree gridded data for precipitation and temperature variables [18]. The impact of climate change on both livestock and their associated resources will be highly variable. For instance, a reduction in the level of precipitation may help reduce the incidence of some animal diseases but simultaneously may reduce grassland productivity [19]. Consequently, the absolute anticipated change in precipitation or exposure was taken, rather than the direction of change. A similar compromise was made by Rees et al. [20]. In an attempt to capture the impact of this change in climate on a particular nation, the absolute changes in precipitation and temperature were weighted by the percentage of a nation's population affected by droughts, flooding and extreme weather events in the preceding 20 years [18] (Equation 3). This aggregated value indicates the strength of the likely impact of climate change. The exposure element of vulnerability also included the expected population growth of a nation [17] as indicator of the future pressure on food and resources, in addition to the annual number of goats formally imported into a nation [17]. This final indicator of exposure indicates the risk of introducing novel disease into the national goat herd. Despite the fact that the true number of imports is likely to exceed this in the non-EU nations (as informal trade cannot be accurately quantified), it is still an important indicator to include. The trade in live animals contributes to a global redistribution of not only infected hosts, but also pathogens and vectors of disease, in addition to the establishment of novel host-pathogen interactions [21].

The indices selected to determine the adaptive capacity of a nation were: the average life expectancy [17] as an indicator of the overall health of the nation; gross domestic product (GDP) [17] as an indicator of the strength of a nation's economy; and governance [22]. The latter indicator is an aggregated index compiled by the World Bank based on the control of corruption in a nation, the government effectiveness of a nation, the political stability and absence of violence or terrorism in a nation, the regulatory quality of a nation, the rule of law within a nation and the voice and accountability of a nation. Further information on this index can be found in Kaufmann et al. [23].

Each indicator was scaled from zero to one on a linear, absolute scale, to allow for the different units in which the indicators were recorded, where zero was the lowest value seen and one the highest. Indicators were not normalised so that the true distribution in indicator values would be reflected in the final vulnerability scores.

Sensitivity (S) was calculated as the sum of food security indicator score (fs), productivity indicator

score (pr) and nutritional contribution indicator score (nc) divided by three to give an average score:

$$S = (fs + pr + nc) / 3 \quad (\text{Equation 1})$$

Exposure (E) was calculated as the sum of the climate change indicator score (cc), population growth indicator score (pg) and imported disease risk score (dr) divided by three to give an average score:

$$E = (cc + pg + dr) / 3 \quad (\text{Equation 2})$$

For the climate change indicators, methods described previously [4] were followed: the absolute projected change for temperature (Δt) was multiplied by the absolute projected change for precipitation (Δp) and weighted through further multiplication by the percentage of a nation's population affected by drought, flooding and extreme weather events in the preceding 20 years (w). This gave a single value (cc) to estimate the likely impact of climate on goat production:

$$cc = \Delta t \cdot \Delta p \cdot w \quad (\text{Equation 3})$$

Adaptive Capacity (AC) was calculated as the sum of health (he), economy (en), and governance (gv) indicator scores, divided by three to give an average score:

$$AC = (he + en + gv) / 3 \quad (\text{Equation 4})$$

These sensitivity, exposure and adaptive capacity scores were then rescaled from zero to one. To obtain an index of vulnerability, both additive and multiplicative models were constructed:

$$V = S + E - AC \quad (\text{Equation 5})$$

$$V = (S \cdot E) / AC \quad (\text{Equation 6})$$

To avoid division by zero, a constant (0.01) was added to the adaptive capacity score of all nations before inclusion in the multiplicative model. Vulnerability was again expressed on a scale from zero to one to allow comparison of nations; a score of zero represents a very low and one a very highly vulnerable nation. The results of the additive and multiplicative models were then compared using Kendall's tau coefficient.

The database of indicators was built in Microsoft Excel 2013. All data analysis was performed using R [24, 25] under the R studio interface version 0.99.473 [26].

Results and Discussion

The scaled sensitivity, exposure, adaptive capacity and overall vulnerability scores and rankings of the 17 nations included in the analysis can be seen in Table 2; Fig. 1-4 show the geographical distribution. There was no significant difference between the results of the additive and multiplicative models ($r_\tau = 0.627$, $z = 3.504$, $p < 0.001$) and hence the results reported here are from the simpler, additive model.

Table 2. Rankings and scores for sensitivity, exposure, adaptive capacity and vulnerability are presented for the 17 Mediterranean nations included in the vulnerability model.

Nation	Vulnerability		Sensitivity		Exposure		Adaptive capacity	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score
Syria	1	1.00	4	0.88	2	0.97	13	0.07
Morocco	2	0.81	2	1.00	11	0.48	14	0.03
Algeria	3	0.66	7	0.62	8	0.54	17	0.00
Israel	4	0.62	1	1.00	6	0.66	4	0.57
Albania	5	0.61	9	0.33	1	1.00	11	0.26
Lebanon	6	0.56	5	0.76	9	0.52	10	0.29
Greece	7	0.47	3	0.99	14	0.33	7	0.50
Egypt	8	0.35	14	0.02	7	0.63	15	0.03
Libya	9	0.28	12	0.03	10	0.49	16	0.03
Croatia	10	0.20	6	0.68	17	0.00	8	0.35
Spain	11	0.13	13	0.02	3	0.96	3	0.77
Tunisia	12	0.09	17	0.00	13	0.35	12	0.20
Turkey	13	0.08	15	0.01	12	0.44	9	0.33
France	14	0.06	11	0.19	5	0.89	1	1.00
Italy	15	0.05	16	0.01	4	0.91	2	0.84
Cyprus	16	0.05	10	0.25	15	0.33	6	0.51
Slovenia	17	0.00	8	0.38	16	0.12	5	0.52

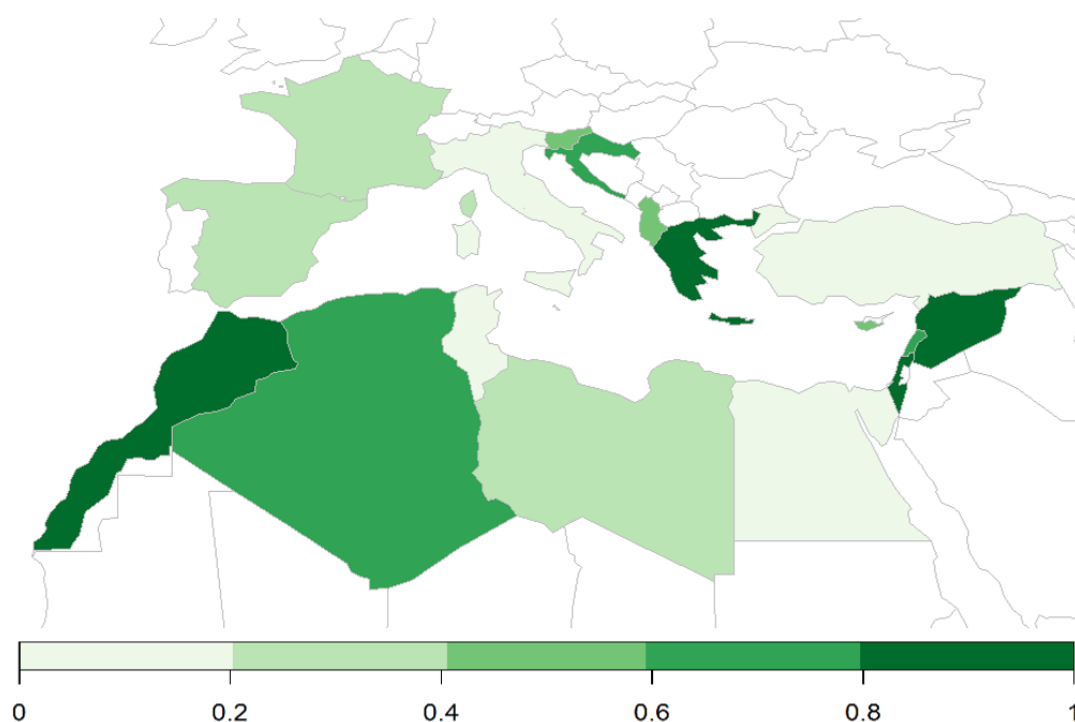


Figure 1. Sensitivity: level of food security, volume of home-produced goat products consumed per capita and productivity of goats in Mediterranean nations. 0 – 1 = low to high sensitivity. Nations not included in the analysis are represented in white.

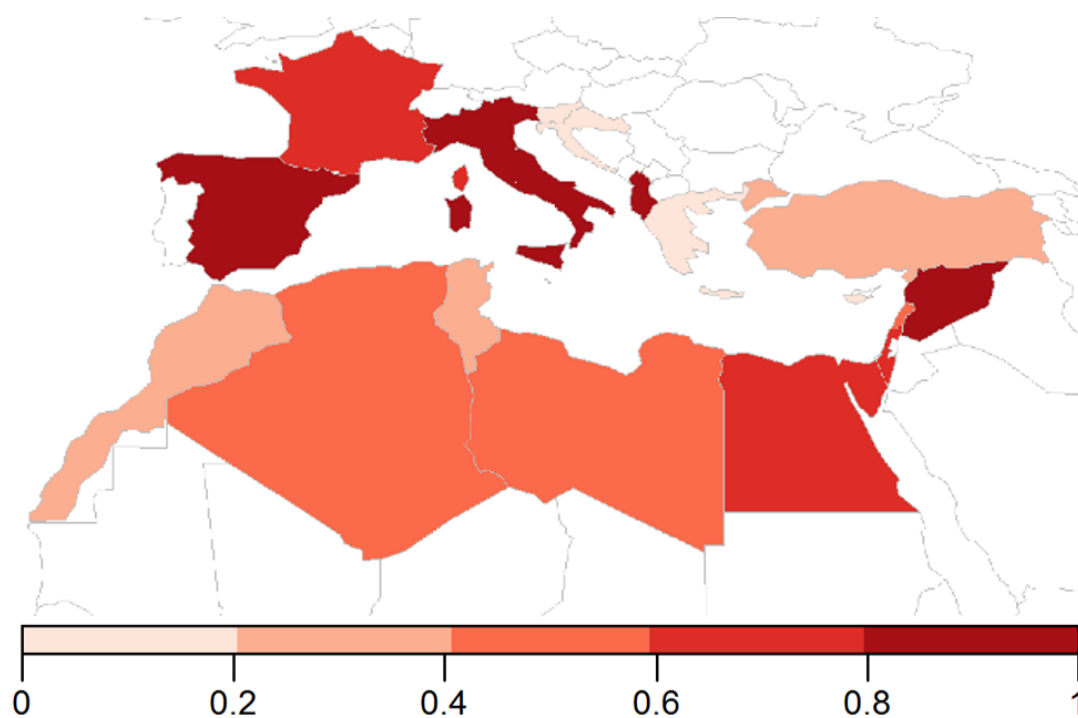


Figure 2. Exposure: impact of projected changes in climate based on the current percentage of population affected by drought, flooding and extreme weather and projected population growth of nations in addition to risk of importing goat disease for the Mediterranean nations. 0 – 1 = low to high exposure. Nations not included in the analysis are represented in white.

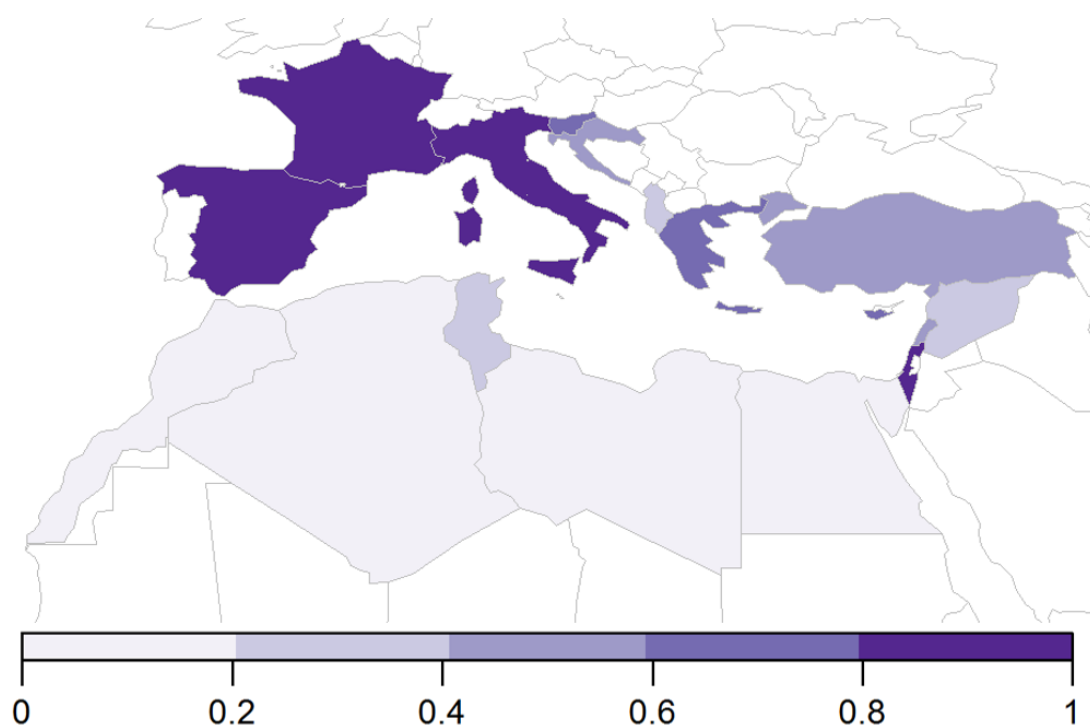


Figure 3. Adaptive capacity: Mediterranean nations' ability to change in response to or cope with changes in climate, food demand and goat disease status based on health, economic and governance indicators. 0 – 1 = low to high adaptive capacity. Nations not included in the analysis are represented in white.

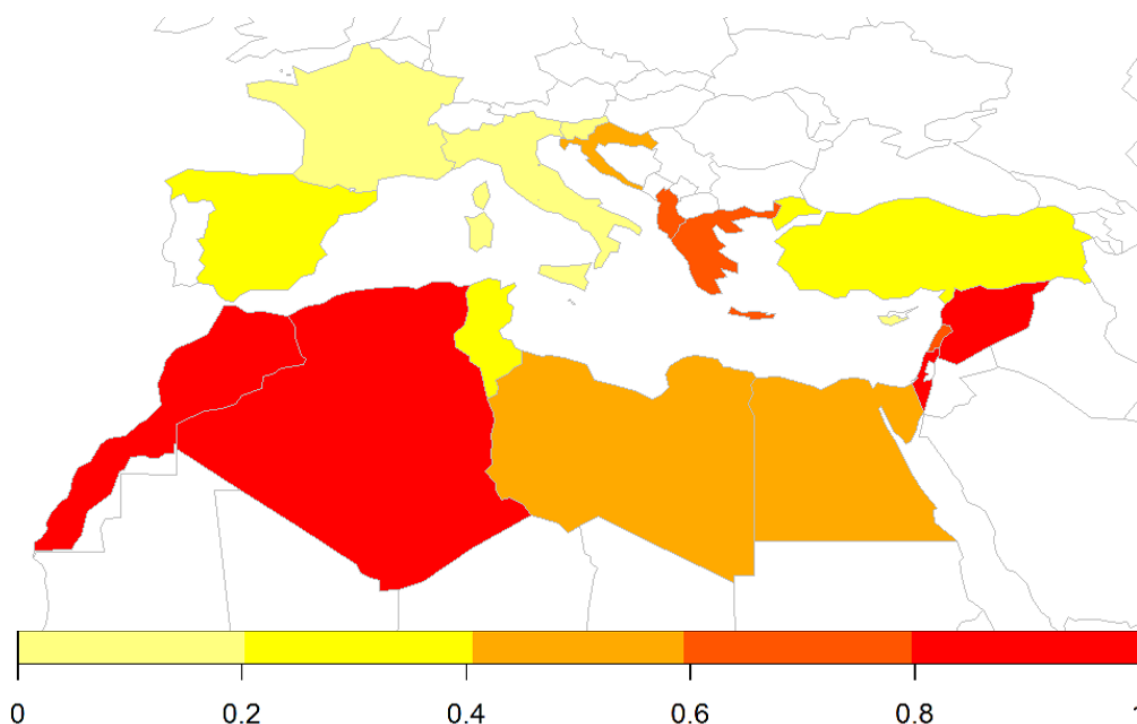


Figure 4. Overall vulnerability of Mediterranean nations to the impacts of population growth, climate change and novel goat disease on goat production and their contribution to food security. 0 – 1 = low to high vulnerability. Nations not included in the analysis are represented in white.

The goat sector of Syria ranked as the most vulnerable (Table 2), although this result has little meaning in the light of current political events. Morocco ranks second for overall vulnerability (Table 2) with high sensitivity (rank two of 17) and low adaptive capacity (rank 14 of 17). This is a result of having the highest food inadequacy score, the lowest human life expectancy and very low goat productivity (rank 16 of 17). The exposure score for Morocco, however, is relatively low (rank 11 of 17).

The most vulnerable member of the European Union (EU) is Greece. It has an overall vulnerability rank of seven (Table 2), despite low exposure (rank 14 of 17). The sensitivity of Greece, however, is high (rank three of 17) and adaptive capacity is the lowest of those within the European Union (rank seven of 17). Greece has the highest score for the volume of goat products consumed per capita. This is despite low productivity of their goats (rank 15 of 17). The risk of importing goat disease is also high (rank four of 17).

The top three ranking nations for adaptive capacity (those with the strongest ability to cope or adapt to the exposures) are France, Italy and Spain (Table 2). These nations have the longest life expectancies and strongest economies (Fig 3). This high adaptive capacity helps to counteract their relatively high exposure scores (ranks three, four and five for Spain, Italy and France respectively). The North African nations have the lowest adaptive capacity (Fig 3). Algeria has the lowest score

followed by Libya, Egypt and Morocco respectively; all four nations have low life expectancies.

The least vulnerable nation is Slovenia (Table 2) despite a sensitivity score in the upper half of the nations (rank eight of 17). Slovenia does, however, hold the second lowest exposure score and has a strong adaptive capacity (rank five of 17).

To summarise, nations with lower food security and more reliance on home-produced goat products to support human nutrition also tend to have a lower adaptive capacity and therefore an exacerbated vulnerability. This highlights the importance of goats in less developed nations. In contrast, some EU nations have a high exposure score due to the number of live goats imported. Despite this they have a lower overall vulnerability due to their strong adaptive capacities. This reflects the need to consider all three elements of vulnerability in unison and that the three elements may have very different contributions to similar vulnerability scores. For instance, Israel and Albania received very similar overall vulnerability scores (0.65 and 0.63 respectively) despite very different sensitivity, exposure and adaptive capacity scores. Consequently, different approaches would need to be taken to reduce vulnerability in each nation according to their main source of vulnerability.

Morocco was identified here as the second most vulnerable nation in this study, which is in agreement with previous work identifying Morocco as the most vulnerable of the North African nations to climate change [16]. Therefore the interaction

between the different elements contributing to its vulnerability will be discussed here in more detail as a useful exemplar to highlight the interactions

between the various components of the system (Fig. 5).

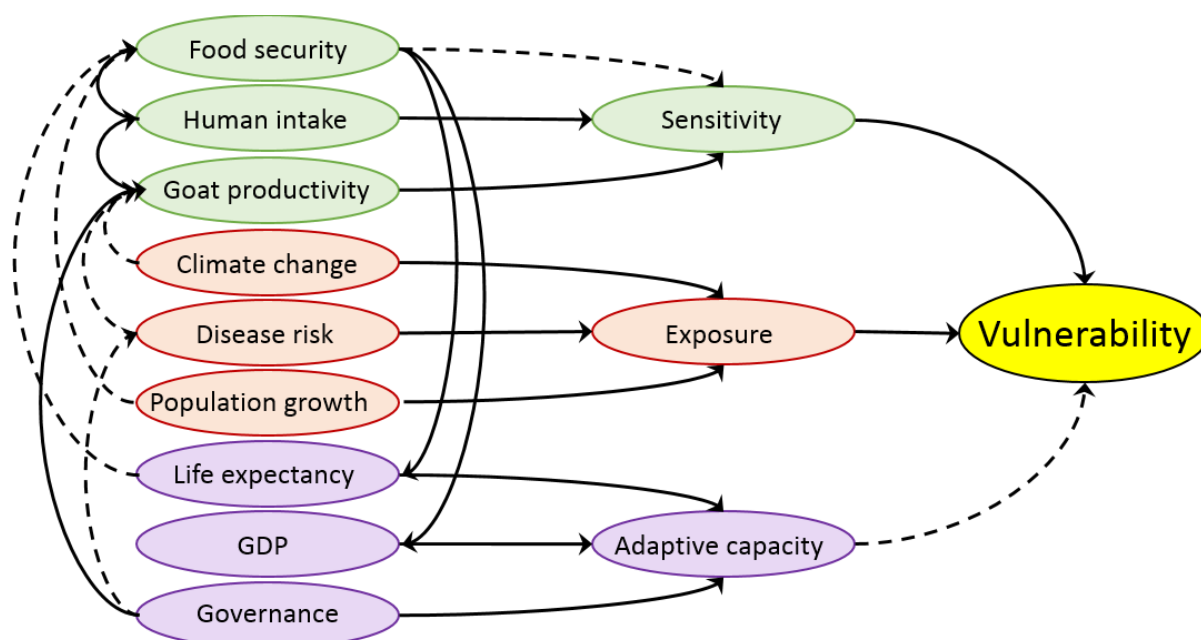


Figure 5. The interaction of the indicators of sensitivity, exposure and adaptive capacity for the prediction of vulnerability in goat production systems. When an indicator is increased, the likely effect on connected indicators is represented by a solid line, and a decrease is represented by a dashed line. The climate change element combines the indicators for predicted change in temperature, predicted change in precipitation and the percentage of a population affected by droughts, flooding and extreme weather events.

The sensitivity of Morocco is driven almost entirely by their lack of food security, for which they rank highest in the Mediterranean (9.3% of the population have an inadequate dietary supply) [17]. Morocco has goats with low productivity (rank 16 of 17), which is in agreement with previous farm level studies [13], and only a small amount of home produced goat products are consumed per capita (rank 13 of 17). This creates a dilemma: one strategy to improve food security would be to increase the amount of goat products available for human consumption by increasing the productivity of goats. However, despite improvements to food security reducing sensitivity, both greater productivity and greater consumption per capita will increase sensitivity and, potentially, increase overall vulnerability. Greater sensitivity will also result from Morocco's exposure to high anticipated population growth (33.8% from 2011 to 2050) [17] and subsequent human food requirements. Additionally, the anticipated impacts of climate change (Morocco ranks fifth of the 17 nations in the study in its sensitivity to climate change factors) may make the higher volumes of animal feed required to support greater goat productivity difficult to source [13]. This will limit improvements. Furthermore, the import of live goats into Morocco is high relative to other Mediterranean regions (rank seven of 17). This is likely to increase exposure to imported

disease, which could further constrain the improvement of goat productivity.

Godber and Wall [4] suggest that increases in adaptive capacity have a proportionally larger effect on reducing vulnerability than the equivalent reduction in sensitivity. Therefore, to support and protect increased productivity, and to counteract any increase in vulnerability, additional measures should be incorporated to improve adaptive capacity. In the model, Morocco's adaptive capacity score is low (rank 14 of 17) with the lowest life expectancy and GDP of the nations in this study. Increasing the productivity of goats and consumption of their products by the Moroccan population to improve food security, could result in a corresponding improvement in life expectancy (due to improved health) and GDP (due to greater employment rate, again through improved health). Direct improvements to adaptive capacity, however, are likely to be more beneficial, particularly through strengthening governance. This could in turn benefit market infrastructure and access to improve profit efficiency for the sector [27].

Governance is currently the strongest element of adaptive capacity in Morocco, but is low when compared to other Mediterranean nations (rank 12 of 17). Therefore the success of stricter government-initiated biosecurity measures to help reduce the risk of exposure to disease, or public authority initiatives

such as the “plan Maroc vert” [28], which disseminates education, training and subsidies to improve agricultural practices, need to be implemented and monitored with care to be successful. Improved infrastructure, stronger supply chains and market networks for the distribution of both inputs and outputs of goat production, also under the influence of governance, could further strengthen the adaptive capacity element in addition to supporting increased goat productivity [11].

Conclusion

This analysis gives a broad overview of the vulnerability of goat production in the Mediterranean region, in terms of the reliance of nations on their own goat products for food security, the exposure of nations to the combined effects of climate change, population growth and goat disease and their adaptive capacity to cope with this exposure. It shows the importance of considering all three elements of vulnerability in unison, and that the three elements may have very different contributions to similar vulnerability scores. Consequently, different approaches would need to be taken to reduce vulnerability in each nation according to their main source of vulnerability. One aspect that the model does not fully capture is the contribution of goat production to the economy of Mediterranean nations, particularly through the sale of dairy products. This is likely to be significant. Nevertheless, using Morocco as an example, this model provides a useful insight into the complex, and often counter-intuitive inter-relationships between livestock productivity and food security and their vulnerability to external constraints. Furthermore, this study focuses on the goat sector, because goat production is highly concentrated around the Mediterranean and has an important socio-economic role, but the model could equally be applied to any livestock production sector.

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