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Decision-making under climate shocks and economic insecurity: Ranching in rural Baja California Sur, Mexico

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ABSTRACT

Climatic shocks and economic insecurity challenge the wellbeing of livestock managers, globally. Scholars argue that ranchers pursue different economic strategies (herd composition and uses) because of the effects of variation in wealth on risk preferences. However, intergenerational wealth transfers and experiences of loss could also explain these outcomes. There are no tests comparing which of these interpretations more closely align with decisions ranchers employ. Accordingly, we examine how ranchers from rural Baja California Sur, Mexico adjust herd compositions and uses across varying economic (i.e. land security) and environmental conditions (i.e. drought vs non-drought years). Our results indicate 1) both socio-economic condition and intergenerational transfers are associated with herd composition – people on secure land and whose parents ranched cattle have more cattle, 2) herd composition influences consumption patterns – people focusing on goat production eat a greater percentage of their livestock relative to those with cattle regardless of ecological condition, 3) socio-economic variation influences sales and maintenance under normal ecological conditions – people living on secure land place proportionally more livestock into sales, while the land insecure focus on maintenance, and 4) experience with drought-induced livestock losses, but not land security, explains variation in how people respond to an ecological shock – those experiencing larger losses place greater effort in keeping herds alive rather than sales, suggesting they become risk averse. Our results indicate that socio-economic variability influences risk preferences under benign ecological conditions; however, these preferences are flexible in the face of economic losses.

1. Introduction

Two major sources of risk to small-scale livestock managers globally are environmental variability and economic insecurity (Faisal et al., 2021; Thornton, 2010; Thornton, Boones, & Ramirez-Villegas, 2015). This is especially true for rural-poor populations residing in arid ecosystems, and other marginal habitats, where limited, infrastructure development (e.g. irrigation), commercial institutions (e.g. markets), and/or government services (e.g. insurance) force individuals to rely on local ecological conditions to support livestock and/or crop production (e.g. dryland agriculture) (Hansen et al., 2019). In these contexts, livestock holders primarily provision animal herds using local vegetation (Grace et al., 2017) whose quantity and quality are influenced by intra- and inter-annual variation in precipitation. In times of drought, fodder becomes both scarcer and of lower nutrient quality leading to a suite of negative livestock outcomes including weight loss, increased susceptibility to disease and parasites, and, ultimately, higher mortality (Thornton et al., 2015; Tolera, Merkel, Goetsch, Sahlu, & Negesse, 2000). Despite the known hazards associated with drought, how households maintain productive herds in response to increasingly unpredictable environments is understudied especially within the evolutionary social sciences (Hazel et al., 2021). Thus, targeting ranchers in Baja Mexico Sur, we seek to examine how small-scale livestock producers variably manage herds as adaptive strategies to cope with the

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impacts of climate shocks and economic insecurity.

To deal with exogenous sources of risk, ranchers employ both *ex-ante* (e.g. modifying herd compositions) and *ex-post* strategies (e.g. reducing food intake or liquidating assets) (Hansen et al., 2019). However, livestock managers are not an undifferentiated mass and socio-economic status, in particular, shapes the strategies people employ to manage environmental shocks (Dercon, 1998; Hansen et al., 2019; Mace, 1990; Mace & Houston, 1989). One source of this socio-economic differentiation, and resultant management strategies, is land ownership (Ho, 2021; Murken & Gornott, 2022). Globally, the world's rural-poor reside on land that is either contested or lacks equitable mechanisms for regularizing property rights (USAID, 2013; Wickeri & Kalhan, 2010). As a result, communities that have lived and worked on the same land across generations nevertheless become "landless populations" (Ashley, 2016). Moreover, benefits to land ownership go beyond the actual market value of an area. For example, those who have clear title, or who can regularize land holdings through cooperatives (e.g., the Mexican *ejido* system), can access a range of benefits, including credit markets, government subsidies, and a level of psychological security that is not available to those who lack it. Consequently, these socio-economic differences fundamentally structure how livestock managers engage with economic markets, embody risk, and manage landscapes (Hansen et al., 2019; Mace, 1990).

1.1. Herd composition, wealth, risk, and intergenerational transmission

One strategy for livestock managers to navigate these complexities is variable herd compositions. Research shows that poorer households typically keep greater numbers of small livestock relative to wealthier households, who are themselves more likely to keep larger-bodied ones - labeled the "Livestock Ladder" in development economics (Mace, 1990; Pica-Ciamarra, Tasciotti, Otte, & Zezza, 2011). This finding has been attributed to the effects of variation in wealth on risk preferences (Hansen et al., 2019; Kuznar, 1991, 2001; Mace & Houston, 1989; Winterhalder, Lu, & Tucker, 1999), as different livestock types (e.g. cattle versus goats) require different upfront and maintenance costs, provide different economic returns at different rates, and have different abilities to cope with environmental stressors (Almadani, Weeks, & Deblitz, 2021; Aziz, 2010; Joy et al., 2020; Pica-Ciamarra et al., 2011). However, two different intellectual traditions, both of which focus on marginal utility theory, have interpreted this relationship in fundamentally different ways. Many economists, following Friedman and Savage (1948) who employed a logit function to describe the relationship between wealth and marginal utility, argue that the poor should be risk-averse, while those in good condition should be risk-prone, because for the poor, the marginal effects of losing a single animal is greater than that gained by an increase of a single unit (Rosenzweig & Binswanger, 1993; Pica-Ciamarra et al., 2011; Carter & Lybbert, 2012; Maass et al., 2014; Price & Jones, 2020). On the other hand, behavioral ecologists relying on the expected energy budget rule (Caraco, Martindale, & Whittam, 1980; Stephens, 1990), apply a sigmoid marginal utility function and predict the opposite – the poorest individuals should be risk-prone because when individuals fall below their daily energy requirements, the payoffs to risk-taking outweigh the consequences of risk-aversion (i.e., starvation) (Winterhalder et al., 1999).

These seemingly contradictory perspectives may simply describe decisions under risk for different points along a wealth spectrum. This can be illustrated using an undulating marginal utility curve with two inflection points that predict risk-preference under starvation, food-secure yet chronically poor, and relatively wealthy conditions (Kuznar, 2001; Tucker, 2017) (Fig. 1). For both the starving and the wealthy, who exist along the concave-upward portion of the curve, the potential utility gains from gambles (the grey dashed lines) are greater than the potential losses (the black dashed lines) – thus favoring risk-proneness. However, for the poor, who exist along the concave-downward portion of the curve, the potential utility losses (the grey dashed line) is greater than the potential gains (the black dashed line) – thus favoring risk-aversion. The sigmoid model may be appropriate for describing populations with variation in wealth and a significant possibility of starvation (e.g. subsistence-based economies), while the logit model may be more appropriate for populations with wealth variation but limited threat of starvation (e.g. market integrated economies). Thus, as it relates to herd compositions, for a population with limited likelihood of starvation, poorer individuals (i.e. those on insecure land) should choose livestock species perceived as less risky, while wealthier individuals (i.e., those with secure land) should pursue livestock species perceived as more risky given wealth-based utility returns.

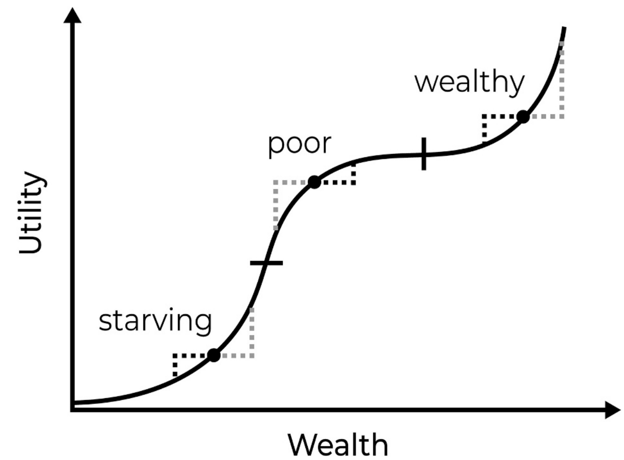

Fig. 1. A hypothetical marginal utility curve with two inflection points and three wealth classes. The starving and the wealthy stand to gain more than lose with gambles, while the for the poor they stand to lose more than they gain (dashed grey lines indicate the maximum gains or losses from a gamble).

While behavioral ecologists and development economists typically explain herd composition as a function of one's immediate socio-economic position, other factors, such as the intergenerational transmission of wealth and knowledge (Borgerhoff Mulder et al., 2010), impact the herds people keep. For example, parents and extended kin can lower the upfront costs to raising large-bodied livestock by gifting animals to children, as is commonly practiced by many pastoral societies (Lesorogol, Chowa, & Ansong, 2011). Thus, in the absence of economic security, individuals may engage more "risky" herd compositions as a result of their family histories. To our knowledge, no research no has examined how immediate economic circumstances and intergenerational transmission of livestock co-determine herd compositions.

1.2. Herd uses, wealth, risk, shocks, and loss

Research also demonstrates that socio-economic variation influences how people allocate their herds to different functions, such as sales, personal consumption, and/or maintenance for restocking herds into the future (Bollig & Vehrs, 2020; Carter & Lybbert, 2012; Deaton, 1991; Hoddinott, 2006; Scott 2019; Sutter, 1987). Poorer households reportedly dedicate a larger fraction of their herds to personal consumption and maintenance, while wealthier households allocate larger fractions of their herds to market sales (Bollig & Vehrs, 2020; Hoddinott, 2006; Sutter, 1987). Climatic shocks may influence how ranchers engage in these activities, leading people from different socio-economic backgrounds to pursue different strategies (Carter & Lybbert, 2012; Deaton, 1991; Hoddinott, 2006; Kazianga & Udry, 2006; Scott 2019; Zimmerman & Carter, 2003). Because droughts cause significant livestock mortality (Thornton, 2010; Thornton et al., 2015; Tolera et al., 2000), households must determine how to allocate surviving animals during these events. If the poor are risk-averse for the reasons outlined above, they should place greater emphasis on maintaining herds into the future at the expense of sales and subsistence, because doing so allows them to maintain their assets and therefore, future income (Zimmerman & Carter, 2003). Alternatively, the experience of economic losses associated from an ecological shock may influence people's perceptions of risk, irrespective of their initial socio-economic status (Brown, Daigneault, Tjernstrom, & Zou, 2018; Lawrence, Quade, & Becker, 2014; Peng, Zhao, Elahi, & Peng, 2021). Natural disasters cause economic losses, which can affect subjective expectations about the future and in turn shape how individuals invest time and energy (Brown et al., 2018). Because natural disasters do not affect all people equally, subjective expectations about future events can diverge, leading individuals to adopt diverse strategies, not because of their pre-disaster socio-economic condition, but rather, because of their unique experience with loss (Gao, Liu, & Shi, 2020). Thus, if economic losses do not push individuals into a lower wealth class, those experiencing greater herd losses as a result of an ecological shock, should be more pessimistic about the future and place greater emphasis on herd maintenance relative to sales and consumption (sensu Price & Jones, 2020).

In sum, revealing the dynamics between socio-economic variability, climate shocks, and agricultural strategies is important for economic and social policy-making regarding the world's impoverished, rural peoples (Carter & Lybbert, 2012). While these themes are typically fodder for development economists and agricultural policy-makers, they are less frequently pursued by evolutionary social scientists despite the linkages between themes like socio-economic variability, decision-making, and behavioral strategies (although see Mace & Houston, 1989; Mace, 1990, 1993; Kuznar, 1991, 2001; Tucker, 2012, 2017). Recently, scholars have called for greater integration of the evolutionary social sciences and applied climate change research (Pisor & Jones, 2021). Our work is positioned within this space to better understand variable livestock management strategies among ranchers in rural Baja California Sur, Mexico. These households are embedded within a desert ecology and are dependent on rainfall for livestock production – rainfall that is increasingly unpredictable. However, despite experiencing similar ecological conditions, producers differ dramatically in their management approaches. Accordingly, in this context of socio-economic and environmental variability, we target the role of land security and drought on livestock management and test the following relationships: 1) does current socio-economic status or parental herd composition explain one's herd composition; 2) does socio-economic status predict herd uses under varying ecological conditions, and 3) does socioeconomic status or projected livestock losses explain the change in behavior across ecological conditions?

2. Materials and methods

2.1. Study site

Baja California Sur (hereafter, BCS) is one of two Mexican states that make up the Baja California peninsula. The dominant geologic feature of BCS is the Sierra de La Giganta mountain range (hereafter, the Giganta). Although the Giganta mountain range is not particularly tall (~1600 m), the narrow width of the peninsula coupled with its recent geologic origins (~15 MYA) (Umhoefer, Dorsey, Willsey, Mayer, & Renne, 2001) make it a notoriously difficult region to traverse. The vast majority of the Giganta is considered a hot, arid to semi-arid ecosystem (Köppen-Geiger BWh) with yearly precipitation totals hovering near 200 mm (Fig. 2a) (Rebman & Roberts, 2012). It is characterized as a southern extension of the Sonoran Desert Biogeographic Region and is dominated floristically by columnar cacti and xeric scrub (Shreve & Wiggins, 1964; Leon de la Luz & Dominguez, 2006). Like the rest of the Baja California peninsula, no active rivers exist in the Giganta (Grismer & McGuire, 1993) and the only naturally occurring surficial fresh water comes from perennial desert springs (Maya, Coria, & Dominguez, 1997; Leon de la Luz & Dominguez, 2006; Lerback et al., 2022) and seasonal rains associated with the North American Monsoon (Hasting & Turner, 1965; Macfarlan et al., 2021; Rebman & Roberts, 2012). Based on weather station data extracted for the southern Giganta, climatic variability and severe droughts have been a common feature of this ecosystem (Fig. 2b). These ecological constraints have dramatically impacted human decision-making and cultural development over time (Crosby, 1981; Macfarlan & Henrickson, 2010; Macfarlan et al., 2021, 2019, 2020; Schacht, Macfarlan, Meeks, Cervantes, & Morales, 2020; Schniter et al., 2021; Lerback, Bowen, Macfarlan, Schniter, & Garcia, 2022).

Although humans have occupied this region for at least the last several thousand years (Henrickson, 2013), the current population is largely descended from Euro-American peoples who first settled the region beginning in the late 17th and early 18th centuries (Macfarlan et al., 2019; Martinez, 1960). These people maintain many of the cultural traditions of their forebearers, including metallurgy, artisanal craft production, and small livestock keeping. They are also some of the least served communities in BCS, lacking paved roads, electric grid, piped water, sanitation, medical facilities, and a range of other infrastructure development (Comision Nacional de Areas Naturales Protegidas, 2014; Kiy, McEnany, & Monahan, 2006). As a result, they are heavily reliant on local ecological conditions for navigating life. Despite these constraints, families are generally healthy and well fed, with daily food consisting of several meals of beans, rice, cheese and flour tortillas. Most households are located within valleys on flat-lands above dry riverbeds

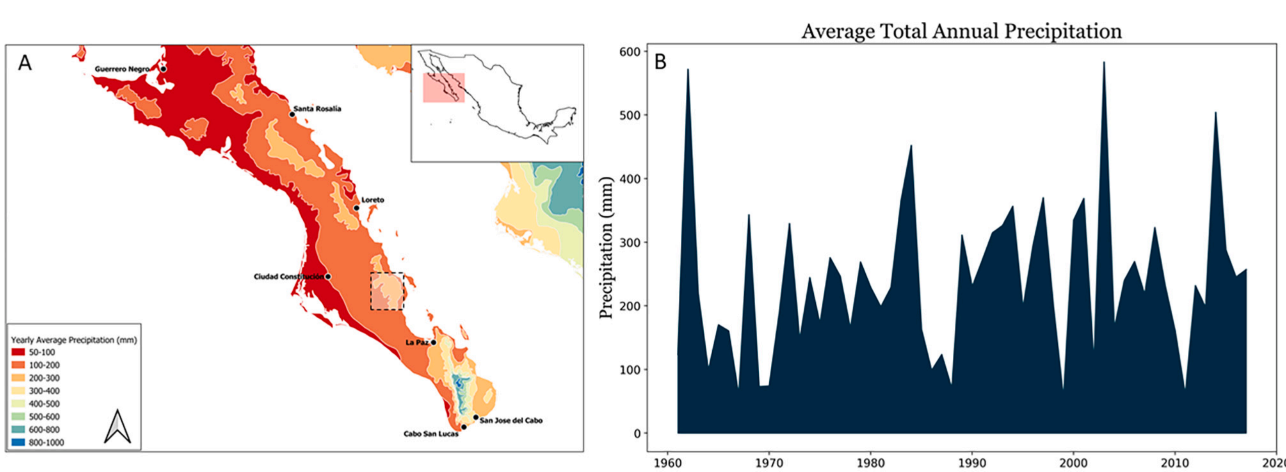

Fig. 2. Precipitation regimes in BCS, Mexico. Panel A: Yearly average precipitation regimes across BCS. Small dashed box is the location of the study site. Panel B: Yearly precipitation variability in the southern Sierra de La Giganta mountain range (the small dashed box).

downstream from a spring, which provision households via gravity fed irrigation (Lerback, Bowen, Macfarlan, et al., 2022; Macfarlan et al., 2020). The predominant economic activity is goat and cattle herding primarily for meat and cheese production. Livestock are used for a variety of purposes including personal consumption, sales on local and urban markets, and as a store of wealth. Whereas goat meat and cheese are considered a regular part of the diet, cattle byproducts are often reserved for special occasions (e.g. weddings, holidays) or for market sales. According to local residents at the time of data collection in 2022, goats, which command $20 (Mexican Peso) per kilogram, net approximately $1000 per animal (expected weight = 50kgs), while cattle, at $24 pesos per kilogram, command $7200 (expected weight = 300kgs). Livestock typically consume native vegetation, with ranchers having specific areas that they exclusively use, typically on a usufruct basis. However, this region has received virtually no rain between the years 2019 and 2022 and inadequate rain since Hurricane Odile in 2014, making livestock provisioning difficult. As a result, some ranchers subsidize livestock diets by purchasing fodder from urban markets or growing feed on small garden plots. Consistent with livestock research globally (Almadani et al., 2021; Aziz, 2010; Joy et al., 2020; Pica-Ciamarra et al., 2011), ranchers agree that goats tolerate drought better, have lower up-front and maintenance costs, and reproduce more rapidly relative to cattle, but provide smaller returns on investment. As such, ranchers consider goats to be a low-risk, low-reward herding strategy, while cattle are considered high-risk, high-reward.

Households exist on a patchwork of property rights regimes - some have clear land title, others are members of land cooperatives (i.e. *ejidos*), while others live on legally contested lands or are considered outright squatters. Households residing on land with clear title, who have paid to register their land with an *ejido* (known as *documento usufructo ejidal*), or who are members of an *ejido* are recognized as having secure land, as they have legal recourse for protecting land claims. These individuals are able to leverage their land for access to credit markets as well as government subsidies. However, those residing on disputed land or who are squatters, lack land security and cannot access these governmental and market-based resources. Conversations with local residents suggest that the major drawback to insecure land holdings is not the fear of losing land per se but rather the inability to access credit and other resources. However, some individuals report growing increasingly concerned about insecure land rights as non-governmental organizations and urban investors purchase property and fence it off.

2.2. Data

Approval to conduct this research was obtained through the Institutional Review Board at the University of Utah (IRB# 00083096) and through written consent from local leaders at the study site. Data were collected in two waves: between December 2021 and January 2022 (wave one), and between June and July 2022 (wave two). During wave one, two authors (JHL and MAA) collected self-report data from 66 adults (mean age = 54 years; min/max = 20/87; 62 men) residing across four communities [Santa Maria de Toris (n-individuals = 24), San Pedro de la Presa (n-individuals = 9), La Higuera (n-individuals = 5), and La Soledad (n-individuals = 18)] on projected herd size and composition, as well as the herding allocation strategies (consumption, sales, and maintenance) under varying environmental conditions (drought vs non-drought years) (Tables 1 and 2). The responses given by participants reflect their lived experience through the most recent three-year drought and their approaches to navigating its complexities. This sample represents 60% of all households within the study region. More individuals engage in goat ranching relative to cattle ranching and ranchers have larger goat herds compared to cattle (as would be expected for organisms with faster life history traits). Fourteen individuals exclusively engaged in cattle ranching, 24 focused exclusively on goats, and 28 employed a mixed herd strategy. During a drought, ranchers expect herd sizes to decrease, losing on average 37 goats and 6 cattle. In order to make herd allocation decisions comparable across livestock type, herds were converted to Livestock Units (LUs) using standards for Central America (1 goat = 0.1 LUs; 1 cow = 0.7 LUs) (FAO, 2011). We then calculated for each individual the percentage of livestock units that were comprised of goats, the expected loss of livestock between normal and drought conditions, and the expected loss of livestock as a percentage of herd size.

Table 1
Descriptive statistics from wave one regarding herd size, composition, and land security across drought and normal ecological conditions.

	n	Mean (SD)	Median	Min/ Max	Yes	No
Goat Herd (Normal)	66	115 (109)	111	0/630	–	–
Goat Herd (Drought)	66	78 (72)	75	0/402	–	–
Cattle Herd (Normal)	66	29 (37)	19	0/192	–	–
Cattle Herd (Drought)	66	23 (35)	11	0/190	–	–
LU[1] (Normal)	66	32 (25)	23	3/134	–	–
LU[1] (Drought)	66	24 (23)	15	2/133	–	–
% LU[a] Composed of Goats (Normal)	66	52 (42)	46	0/100	–	–
% LU[a] Composed of Goats (Drought)	66	52 (42)	46	0/100	–	–
Expected Loss of LUs (Normal-Drought)	66	7.8 (8.7)	5	-19[b]/ 35	–	–
Expected % Loss of LUs (Normal-Drought)	66	26 (20)	28	-42[b]/ 71	–	–
Land Secure	66	–	–	–	20	46

[a] LU = Livestock Units.
[b] Two individuals expected herd sizes to increase during a drought.

Between June and July 2022, a second wave of data was collected by SJM, CD, AY, FJHL, and MAA from 44 households across three communities [Santa Maria de Toris (n-households = 35); La Higuera (n-households = 5); San Pedro de La Presa (n-households = 4)]. Of the 66 individuals interviewed in wave one, 46 are represented by this household-level data from wave two. This sample represents 92% of all households within these three communities. Data collection focused on the household's current livestock holdings, whether or not the parents of the heads of household herded cattle, as well as the economic strategies households employed for navigating the most recent three-year drought (Table 3). Furthermore, we used this opportunity to clarify the land security status of all households in the study region, including the individuals represented in wave one and two. Households were considered to be land secure if they either had clear title to their land, their home was located on land with clear title, if they were registered members of an *ejido*, or if they paid to have their land registered with an *ejido* (*document usufructo ejidal*). All others were considered land insecure as their homes lacked legal documentation to protect land rights. Currently, all land is contested in the communities of San Pedro de la Presa, La Higuera, and La Soledad; however, Santa Maria de Toris has a mix of private, *ejido*, and contested land. Similar to wave one, we transformed herds into livestock units and then calculated the percent of livestock units composed of cattle for each household.

2.3. Analytic modeling

We employ a suite of statistical models in STATA/IC 15.0 (StataCorp., 2019) to understand the factors influencing herding decisions. All data for replicating our analyses have been anonymized and are available via the associated Supplementary Material file.

Table 2
Herd allocations by environmental conditions (wave one).

	n[a]	Mean (SD)	Min/Max	n[b]	Mean (SD)	Min/Max	n	Mean (SD)	Min/Max
	Goat			Cattle			Livestock Units		
				Normal Year					
#Eaten	52	9 (7)	0/30	42	1 (1)	0/4	66	1 (0.8)	0/4
#Sold	52	38 (35)	0/150	42	11 (9)	0/40	66	8 (6)	0.2/28
#Kept	52	99 (72)	10/450	42	34 (30)	1/150	66	23 (19)	2/105
% Eaten	52	7 (5)	0/23	42	2 (2)	0/8	66	4 (3)	0/14
% Sold	52	24 (12)	0/60	42	23 (11)	0/50	66	24 (9)	2/46
% Kept	52	69 (11)	36/89	42	75 (12)	50/100	66	60 (12)	36/96
				Drought Year					
#Eaten	52	4 (4)	0/16	42	0.2 (0.5)	0/2	66	0.4 (0.5)	0/2
#Sold	52	22 (19)	0/90	42	9 (11)	0/40	66	6 (7)	0/28
#Kept	52	72 (52)	7/300	42	27 (29)	1/150	66	18 (18)	2/105
% Eaten	52	5 (4)	0/23	42	0 (1)	0/5	66	3 (3)	0/16
% Sold	52	21 (13)	0/58	42	23 (17)	0/50	66	23 (13)	0/50
% Kept	52	74 (14)	38/100	42	77 (17)	48/100	66	63 (18)	33/100

[a] Fifty-two individuals had at least one goat.
[b] Forty-two individuals had at least one cow.

Table 3
Descriptive statistics associated with wave two data collection.

	N	Mean (SD)	Median	Min/ Max	Yes	No
Goat Herd Size	44	66 (44)	70	0/200	–	–
Cattle Herd Size	44	18 (18)	14	0/80	–	–
Livestock Units	44	19 (14)	18	2/76	–	–
% Livestock Units Composed of Cows	44	53 (33)	63	0/100	–	–
Land Secure	44	–	–	–	19	25
Ego's Parents Herded Cattle	44	–	–	–	38	6

3. Results

3.1. Does land security or family history of cattle ranching better explain current herd composition?

We begin our analysis with an examination of the relationship between land security, family histories of cattle ranching, and herd composition. If the relatively poor (land insecure) are risk-averse, then they will pursue small livestock (goats) relative to large livestock (cattle), while the wealthier should do the opposite. However, these relationships may be conditioned on the intergenerational transmission of livestock. To assess these predictions, we use wave two data on household-level herd composition. The outcome variable is the percentage of livestock units composed of cattle. The independent variables are whether or not the house exists on secure land (1 = yes; 0 = no) and if the household heads' parents ranched cattle (1 = yes, 0 = no). Our modeling framework relies on fractional regression, using a logit link function and robust standard errors (RSE), with coefficients reported as Odds Ratios (OR). According to our model (Model Wald $X^2 = 9.6$; $p = .008$; $n = 44$), both land security [OR(RSE) = 2.62(1.1); $p = .018$] and a family history of cattle ranching [OR(RSE) = 3.47(2.3); $p = .056$] are positively associated with the percent of an individual's herd dedicated to cattle.

3.2. What explains what people do with their herds under varying ecological conditions?

Research typically demonstrates that resource insecure households allocate a greater fraction of livestock to both personal consumption and maintenance, while those with greater resources allocate more to sales during normal ecological conditions. This could be the case during droughts, as well, or it is possible that poorer households increase herd maintenance at the expense of sales and personal consumption during droughts to achieve a critical threshold of assets for future use (Zimmerman & Carter, 2003). To assess these predictions, we use wave one data on individual-level perceptions about livestock uses during varying ecological conditions (drought vs. non-drought conditions). The outcome variable for each analysis is the percent of livestock units dedicated to each use: personal consumption, sales, and maintenance. The independent variables include land security (1 = yes; 0 = no) and the percentage of the herd composed of goats. We include the latter variable to determine if different herd compositions have different functions separate from land security. We employ fractional regression, using a logit link function and clustered robust standard errors (CRSE) (grouped around ranch ID), with model coefficients reported as Odds Ratios (OR). According to our models, under normal ecological conditions, land security is not associated with the percent of livestock units dedicated to personal consumption; however, herds composed of a greater percentage of goats are (OR = 3.06; $p < .001$). Conversely, under normal conditions, land security is associated with both the percentage of livestock dedicated to sales (OR = 1.52; $p < .001$) and maintenance (OR = 0.67; $p < .001$), but herd composition is not (Table 4). Taken together our results suggest that during normal ecological conditions, resource insecure households place a greater fraction of their herds to long-term maintenance, while resource secure households divert a greater percentage to sales.

Consistent with the previous analysis, under drought conditions, the percentage of livestock units allocated to personal consumption is associated with herds dominated by goats (OR = 8.46; $p < .001$). However, no other variable is associated with any other outcome

Table 4
Regression coefficients associated with percentages of livestock allocated to different functions during non-drought conditions.

	OR (CRSE)	Z	p
Percent Livestock Units Eaten[a]			
Percent Livestock Units as Goats	3.06 (0.7)	5.1	<0.001
Secure Land (1 = Yes, 0 = No)	1.05 (0.2)	0.3	0.76
Constant	0.02 (0.01)	−18.5	<0.001
Percent Livestock Units Sold[b]			
Percent Livestock Units as Goats	1.05 (0.1)	0.4	0.67
Secure Land (1 = Yes, 0 = No)	1.52 (0.1)	4.2	<0.001
Constant	0.27 (0.02)	−19.2	<0.001
Percent Livestock Units Maintained[c]			
Percent Livestock Units as Goats	0.91 (0.1)	−0.7	0.49
Secure Land (1 = Yes, 0 = No)	0.67 (0.1)	−3.6	<0.001
Constant	1.82 (0.1)	8.7	<0.001

[a] Model Wald X^2=31.3; $p < .001$; n-observations = 66; n-groups = 59.
[b] Model Wald X^2=17.8; $p = .0001$; n-observations = 66; n-groups = 59.
[c] Model Wald X^2=13.2; $p = .001$; n-observations = 66; n-groups = 59.

Table 5
Regression coefficients associated with percentages of livestock allocated to different functions during drought conditions.

	OR (CRSE)	Z	p
Percent Livestock Units Eaten[a]			
Percent Livestock Units as Goats	8.46 (3.5)	5.2	<0.001
Secure Land (1 = Yes, 0 = No)	1.22 (0.3)	0.7	0.48
Constant	0.01 (0.003)	−12.6	<0.001
Percent Livestock Units Sold[b]			
Percent Livestock Units as Goats	0.78 (0.2)	−1.1	0.26
Secure Land (1 = Yes, 0 = No)	1.25 (0.3)	0.9	0.32
Constant	0.32 (0.1)	−6.8	<0.001
Percent Livestock Units Maintained[c]			
Percent Livestock Units as Goats	1.15 (0.3)	0.6	0.56
Secure Land (1 = Yes, 0 = No)	0.83 (0.2)	−0.8	0.45
Constant	1.71 (0.3)	3.1	0.002

[a] Model Wald X^2=32.7; $p < .001$; n-observations = 66; n-groups = 59.
[b] Model Wald X^2=2.6; $p = .27$; n-observations = 66; n-groups = 59.
[c] Model Wald X^2=1.03; $p = .59$; n-observations = 66; n-groups = 59.

(Table 5). A post-hoc analysis of variance shows that variance increases for both sales [W = 7.5; d.f. (1,130); $p = .007$] and maintenance [W = 8.5; d.f. (1, 130); $p = .004$] during a drought, suggesting that people show diverse responses to a drought with some increasing sales and others increasing maintenance. However, this is not the case for personal consumption [W = 0.0003; d.f.(1, 130); $p = .99$].

3.3. What explains behavioral change between ecological conditions?

Based on the previous analyses of variance, it appears that people change the decision calculus regarding herd uses between drought and non-drought conditions, with some projecting to increase sales and others maintenance. It could be that land security influences how people engage in these activities, or it could be those who experienced the greatest losses became increasingly pessimistic about the future and decided to increase herd maintenance at the expense of sales to maintain a critical threshold of assets. To answer this question, we employ Generalized Estimating Equations, examining the percent change in livestock units sold and maintained. All our models rely a Gaussian distribution, identity link function, and exchangeable correlation structure. We nest the responses at the level of the household and use robust standard errors (RSE). The independent variables include land security and the expected percent of livestock lost between normal and drought years. Our models indicate that change in livestock uses are not associated with land security (Table 6), but rather they are associated with expected livestock losses (Fig. 3). That is, people who experienced significant livestock losses during a drought are associated with an increase in maintenance at the detriment to sales.

4. Discussion

We performed this research to understand how socio-economic and environmental variability influence herding decisions. One goal was to assess whether current socio-economic condition or historical forces better explained herd compositions. Our second goal was to determine how relative socio-economic status and the experience of economic loss following a drought influenced livestock uses. Both findings speak to historical and contemporary issues in behavioral ecology, evolutionary psychology, and economics regarding wealth, risk, and exogenous shocks (Stephens & Krebs, 1986; Mace & Houston, 1989; Winterhalder et al., 1999; Kuznar, 1991, 2001; Tucker, 2012, 2017). With respect to herd composition, we find that both land security and family ranching histories are associated with herd composition – people with secure land and whose parents herded cattle have proportionally more cattle. With respect to herd uses, we find that 1) herd composition influences how people consume their herds – people who focus on goat production eat a greater percentage of their livestock relative to those with cattle regardless of ecological condition, 2) during non-drought conditions, land security influences decisions regarding sales and maintenance – people living on secure land place proportionally more livestock into sales, while those residing on insecure land place more into maintenance, and 3) expectations about loss of livestock during a drought explains variation in how people respond to it – those experiencing larger losses dedicate a larger percentage of their herds to maintenance (at the expense of sales) relative to those who expect small loses. We leverage theory on risk preferences, wealth transfers, and ecological shocks to explain why these relationships hold and situate them within an applied evolutionary anthropological framework.

A major goal of this paper was to determine the manner in which socio-economic variation influenced how people engaged in risk management through an analysis of livestock manager's ranching decisions. Behavioral ecologists have argued that relatively poor agriculturalists should be risk prone (Mace, 1990, 1993; Mace & Houston, 1989; Winterhalder et al., 1999), while economists have argued they should be risk averse (Carter & Lybbert, 2012; Maass et al., 2014; Price & Jones, 2020; Rosenzweig & Binswanger, 1993). These different predictions emerge because they represent different perspectives on the shape of the curve describing the relationship between wealth and utility. Behavioral ecologists have relied on a sigmoid function to describe this relationship, predicting that the poor will seek risky gambles when one's mean energetic returns is lower than their starvation threshold (Mace, 1990; Mace & Houston, 1989; Tucker, 2017; Winterhalder et al., 1999). Economists, relying on a logit function, argue the relatively poor should be risk averse because gambles can cause individuals to move from being simply poor to completely destitute (Carter & Lybbert, 2012; Maass et al., 2014; Price & Jones, 2020; Rosenzweig & Binswanger, 1993). With respect to herd compositions at this rural study site, goats are perceived as less risky relative to cattle. Because this population is increasingly market integrated, has significant socio-economic variability, and has not experienced a recent history of starvation, we expected the poor to be risk averse compared to the relatively wealthy – as argued by development economists. Consistent with this perspective, we find that people with secure land (i.e. the relatively wealthy) have more cattle (either exclusively or as part of a mixed herd strategy) than those on insecure land, who are themselves more likely to keep goats. Goats are an attractive economic investment for the poor because they require lower maintenance costs, are more robust to environmental shocks, and their natural growth rate is faster than large livestock, supporting long-term household survival through a steady supply of small, short-term economic returns. Conversely, individuals with secure land can more easily engage in a high-risk activity with substantial economic benefits over the long-run - cattle herding – because they have access to resources that allow them to buffer shocks, consider future conditions relative to the present, and make long-term investments. Many families pursue a diversified herding portfolio composed of many goats and a few cattle. Conversations with ranchers suggest the reason they do this is because goats provide security in case of a drought, while cattle can be leveraged to move into a new wealth class if ecological conditions are consistently

Table 6
Regression coefficients associated with the percent change in behavior between normal and drought years.

	B (RSE)	Z	p
Percent Change in Livestock Units Sold[a]			
Secure Land (1 = Yes, 0 = No)	−4.4 (3.5)	−1.2	0.21
Expected LU Loss (% herd size)	−25.5 (5.7)	−4.4	<0.001
Constant	7.1 (1.9)	3.7	<0.001
Percent Change in Livestock Units Maintained[b]			
Secure Land (1 = Yes, 0 = No)	6.8 (4.9)	1.4	0.17
Expected LU Loss (% herd size)	37.6 (8.6)	4.4	<0.001
Constant	−9.3 (2.8)	−3.3	0.001

[a] Model Wald X^2=20.2; $p < .0001$; n-observations = 66.
[b] Model Wald X^2=19.7; $p < .0001$; n-observations = 66.

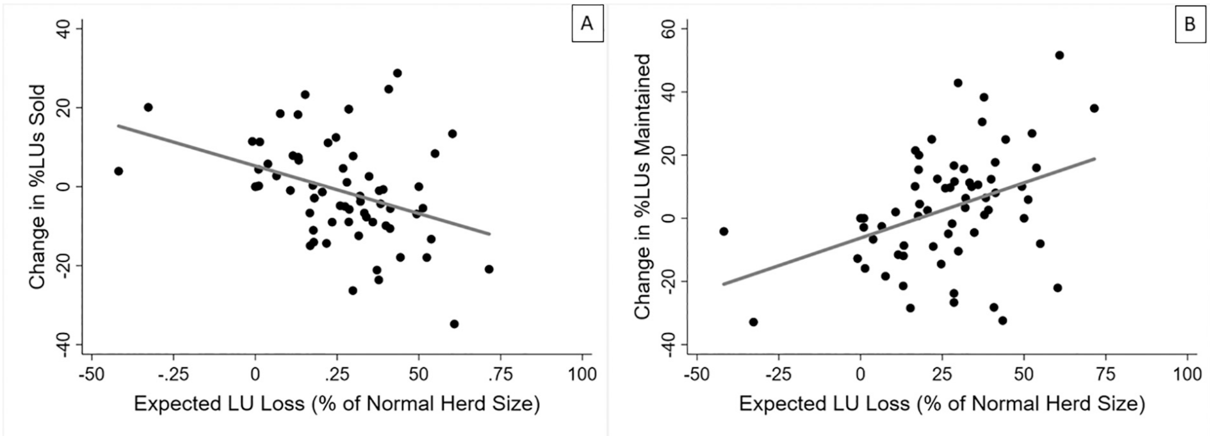

Fig. 3. Scatter plot relationships between expected herd losses and change in livestock allocations. Panel A shows this relationship for sales. Panel B shows this for maintenance. LU refers to "Livestock Units".

good across years. These individuals might be best understood as existing at an inflection point between then relatively poor and wealthy, and who employ both risky gambles and bet hedging simultaneously (Friedman & Savage, 1948).

While herd compositions may be reflective of how relative wealth differentials influence risk (e.g. Dercon, 1998; Kuznar, 1991, 2001; Maass et al., 2014; Mace, 1990, 1993; Mace & Houston, 1989), this perspective fails to consider how people's immediate condition is in part determined by historical forces (sensu Winterhalder, Kennett, Grote, & Bartruff, 2010). In the context of pastoralism, it is difficult for people to immediately adjust herd sizes and compositions as these require both capital (to purchase novel livestock species) and time (for herd growth). Furthermore, it is normative in many pastoral societies to gift livestock to children so that they may learn about herding and to support their economic transition to adulthood (Borgerhoff Mulder et al., 2010). As a result, individuals may maintain diverse herding portfolios irrespective of their immediate socio-economic condition because of the intergenerational transmission of wealth. Our research shows that both socio-economic variability and historical forces are related to livestock compositions. These findings provide a novel mechanism to explain why some resource insecure households maintain riskier herd portfolios than what is normally expected given their current socio-economic condition (*contra* Kuznar, 2001). The poorest households may not adopt the riskiest strategies because they have nothing to lose, but rather, their risky livestock portfolios may be a legacy effect related to parental conditions and decisions. To our knowledge, this is the first test of these relationships, and we hope future comparative studies can more fully disentangle how they operate.

Research in development economics suggest that socio-economic variation can shape how people use livestock (Bollig & Vehrs, 2020; Carter & Lybbert, 2012; Deaton, 1991; Hoddinott, 2006; Scott 2019; Sutter, 1987). Consistent with this perspective, we find that under benign ecological conditions, those with secure land place larger percentages of their herds into sales, while those with insecure land focus on herd maintenance. The latter finding has been interpreted as a form of bet hedging on the part of the poor to increase long-term household survival through asset maintenance (Zimmerman & Carter, 2003). Within the study site, individuals with secure land tenure are often required to travel to urban centers to receive economic subsidies and to maintain their land and water rights. Doing so, likely causes these individuals to associate with markets, and therefore sales, more so than those with insecure land.

Negative ecological shocks, such as drought, can result in significant economic losses, which causes people to recalibrate how they manage resources following these events (Brown et al., 2018). As a result, it was not initially clear whether one's initial socio-economic status continues to exert an influence on risk taking following a shock or whether the experience of economic loss itself does so. If the poor are risk averse because they employ pessimistic probability weighting (Maass et al., 2014; Price & Jones, 2020; Rosenzweig & Binswanger, 1993), they should continue to place a greater percentage of their herd into maintenance rather than consumption or sales during a drought. Interestingly, our statistical models do not support this perspective, as variability in land security did not predict how people allocate herds during droughts. Instead, we find that people's perceptions about herd allocations are conditioned on their expectations of loss. Individuals who expected to lose a substantial fraction of their herds during a drought were more likely to up-regulate herd maintenance at the expense of sales, and vice versa for those expecting smaller loses. These findings are consistent with an emerging line of inquiry about the influence of natural disasters on risk perception (Brown et al., 2018; Lawrence et al., 2014; Peng et al., 2021). Natural disasters give rise to economic losses, which can affect subjective expectations about the future and in turn shape how individuals invest time and energy (Brown et al., 2018). Because natural disasters do not affect all people equally negatively, their subjective expectations about future events can diverge, leading individuals to adopt diverse strategies, irrespective of their socio-economic condition (Gao et al., 2020). Our findings suggest that people who expect (or have experienced) substantial losses become more risk averse. These findings suggest that socio-economic variability can influence preference structure, but only under benign ecological conditions, and that these preferences are flexible in the face of economic losses.

Last, our results show that herd composition influences consumption patterns. People who focus on goat production eat proportionally more livestock than those who ranch cattle. This finding aligns with much research that shows that small-livestock keeping is often associated with subsistence and large livestock keeping is associated with market sales (Bollig & Vehrs, 2020; Hoddinott, 2006; Sutter, 1987). Unfortunately, during droughts ranchers reduce the amount of livestock they consume, eating approximately half as many livestock as they normally would. The reduction of food intake can result in significant negative health outcomes, especially among the most vulnerable households (Bollig & Vehrs, 2020; Grace et al., 2017), leads to increasing inequality, and perpetuates poverty traps (Zimmerman & Carter, 2003).

Our analyses and interpretations come with several caveats. As is typical of small populations (Macfarlan et al., 2020), our sample sizes are small. As a result, we have omitted some variables that could be included in analyses (e.g. age, sex) because of issues regarding statistical power. However, as a percentage of the entire meta-population our coverage is substantial (~60% of all households were included in our study). Furthermore, we do not have information from the ranchers themselves on the proximate reasons and goals for their herd compositions. Instead, we deduce this information using theory, previous research, and statistical analyses. A more complete analysis of the relationship between risk-preferences, loss, and herding decisions would include both proximate and ultimate causation – something we hope to accomplish in the future. Last, we opted not to use economic experiments to elicit preferences. Rather we relied on an ethnographically relevant context that was important to the ranchers themselves to study these relationships. This was in part motivated by community members (two of whom are co-authors on this manuscript - MAA and FJHL) who suggested our team orient research questions and methods to phenomenon about which deeply mattered to their communities. While pursuing such an analytic strategy means we lack an independent means for assessing risk preferences, doing so improved people's ability to understand and answer questions, and promoted a more equitable experience in the research process itself.

In conclusion, the livelihoods of the world's rural livestock herders are becoming increasingly negatively impacted by both economic insecurity and climate shocks. This is particularly true in rural BCS, Mexico. Understanding how and why these people employ the strategies they do to overcome these challenges is important for both improving policy making and for theory development. Our analyses provide evidence that socio-economic variation influences how rural herders engage in economic decision-making involving risk and uncertainty; however, it also highlights the importance of wealth transfers and economic losses as potentially important mechanisms for understanding these phenomena. Socio-economic variation and wealth transfers influence who engages in high (or low) risk, high (or low) reward herding strategies, but the experience/expectation of substantial economic loss due to a natural disaster causes people to consider future risk more acutely, irrespective of initial wealth class. We hope our analyses spur greater integration of development economic research with evolutionary social science theory to tackle applied issues with large implications for theory development.

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Declaration of competing interests

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

The data associated with this research are available in the associated Supplementary Information file labeled SI-Data.

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Appendix A. Supplementary data

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