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Why Analyze Mental Models of Local Climate Change? A Case from Southern Mozambique

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ABSTRACT

People construct mental models of local climate change based on their observations and experiences of past climate events and changes. These mental models offer critical insight into locally important factors that trigger responses to new climate conditions and can be used to ground-truth regional climate models. In this paper, the authors explore mental models of changes to local climate patterns and climate-associated environmental changes over the past 45 years (1963–2008) in two rural communities in Matutúine District, Mozambique. Interview results are compared to data from a regional weather station. Residents discuss temperature increases, short-term and long-term precipitation changes, and altered seasonal timing. Measurable climate change in this region includes increasing temperatures and more erratic rainfall leading to drought and altered season timing. The climate-associated environmental changes residents observed draw attention to links between local livelihood practices and climate, as well as emphasize changes that would not necessarily appear in regional climate models. Such changes include reduced crop and wild fruit production, fewer cattle, variable forest size, increased wildfires and elephant conflict, drying up of water sources, poor health, and cultural change. Differences between adjacent communities highlight the potential interaction of landscape and vegetation variability, gender, and livelihoods in observations and experiences of climate change and demonstrate how mental models can provide insight into local ecological patterns and processes.

1. Introduction

Faced with overwhelming evidence for global climate change, the focus of research and policy has shifted toward understanding the mechanisms driving changes, climate change effects at regional scales, and how human communities must adapt to survive. However, the coarse resolution of current climate modeling efforts is frequently inappropriate for policy and intervention efforts (Cash et al. 2006; Wilbanks and Kates 1999). Global and regional scales fail to capture how local climate may vary over complex terrain. Some interactions among climate, environment, and human communities are not readily observed in the datasets used for regional climate models (Magistro and Roncoli 2001), and influential parameters affecting the reactions of individuals and communities as they encounter new conditions may be ignored, misunderstood, or remain unknown (Rayner 2003). As people interact with changing environmental conditions, they construct mental models reflecting their personal observations and experiences and containing locally important parameters (Barsky et al. 2008; Berkes 1999; Paolisso 2002; Patt and Schröter 2008; Salick and Byg 2007). We suggest that an analysis of mental models of local climate change can be used to ground-truth regional climate change models and to provide crucial insight into locally relevant climate and climate-associated environmental change parameters and human–environment interactions.

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As in our field research, we first investigate the climate and climate-induced environmental changes residents of Matutúine District, Mozambique, observed and experienced between 1963 and 2008, and connections between these changes to daily life that residents make. We then compare their mental models of local climate change with climate data from a regional weather station to explore similarities and differences between residents' models of change and trends observed in regional climate data. Rainfall, in particular, plays a key role in regulating vegetation production and distribution in southern Mozambique (Rutherford and Westfall 2003). Subsistence dependency on domestic and wild vegetation suggests that residents of Matutúine District would be keenly aware of any climate and climate-associated environmental changes affecting their survival. In light of projected impacts to food security and disaster risk for this region, specific details about how populations have been, and expect to be, affected by climate change are important for planning and policy.

2. Modeling to increase understandings of local experiences, responses, and vulnerabilities

Studying in situ ways of knowing opens a door to observations and experiences that can speak to living under changing climate conditions. These ways of knowing are cognitive models encompassing

> a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (Berkes 1999, p. 8).

Model holders use their understanding to manage available resources and respond to changing environmental conditions, as demonstrated in Paolisso's (2002) study of Chesapeake Bay watermen or Barsky et al.'s (2008) research with Argentine farmers. Elements included in a conceptualization of local climate change are those of primary importance to the production and survival of the community and its culture. Relationships among various physical, ecological, and social elements of the system as they interact with each other under changing climate conditions are also of interest (Berkes 1999; Doyle and Ford 1997; Nichols et al. 2004; Salick and Byg 2007). Expectations of normal climate and environmental conditions may be explicitly stated or implied in the comparisons, generalizations, and conclusions people make. Mental models of local climate change, then, are a summative conception of all a community's climate knowledge based on their observations and experiences of past and ongoing climate variability. Analyzing mental models of local climate change should therefore increase site specific understandings of experiences and responses to historic, ongoing, and future changes, as well as highlight vulnerabilities to interacting climatic and other environmental stressors.

Regional models identify key aspects of climate and environmental change that governments and aid agencies must address while preparing populations for change impacts. However, the resolution of these models treats regions as physically, ecologically, and culturally homogeneous (Magistro and Roncoli 2001). Casciarri's (2008) research in southeastern Morocco shows that nomadic herders and sedentary farmers living in the same valley perceive drought differently and use disparate, but interrelated, strategies to cope with this environmental stress. Sometimes the needs of policymakers and resource managers to achieve intervention goals may further bias model parameters, data input, and analysis. For example, Rayner (2003) found that U.S. water managers are reluctant to include new climate forecast data, despite improvements to decision-making ability, if it meant accepting increased responsibility and blame for water supply failure. Gendered aspects of livelihood activities and socially constructed roles, rights, and responsibilities strongly suggest differences in perceptions of and responses to climate changes as well (Dankelman et al. 2008; Nelson et al. 2002). Such model and user biases contribute to misunderstandings of significant climate and environmental changes at a human scale. Research with indigenous and other traditional communities indicates that in situ ways of knowing about local climate change can be used to ground-truth regional models, provide crucial insight into locally important environmental processes not readily observed in datasets or at larger scales, and give commonly underrepresented communities a voice in the greater climate change discussion (Nichols et al. 2004; Salick and Byg 2007). Integration of regional models and mental models of local climate change offers a more valuable, holistic view of past, present, and future human–environment relations.

Remote sensing studies use field-collected data to "ground-truth" (i.e., validate and calibrate) image content prior to analysis. In this sense, mental models can ground-truth regional models by verifying the presence and extent of climate changes at a particular locality. Locals record trends and major events, often within the context of their livelihood activities. Climate change observations by farmers in China and Burkina Faso correlate closely to trends produced from instrumental data despite extensive interannual rainfall variability that was predicted to cause confusion (Hageback et al. 2005; West et al. 2008). The extent and duration of household-level economic diversification, migration, and long-term changes to agricultural practices made by these farmers validates the predictions made by regional models. In some cases, nonclimate variables are the primary signals of change. Vedwan and Rhoades (2001) found that apple growers in northern India recognize changes in onset, duration, and intensity of snowfall relative to the effects on crop growth and production. Mental models of local climate change also speak to local vulnerability by incorporating social stability, livelihood, and other social elements that are difficult to capture in the homogeneity of regional models. Bharara (1982) documented the perception of Indian villagers that ''[d]rought is not simply the dearth of rain (though everyone knows that rain would remove it)—it is the total quality of life, including, besides weather, animal behavior and social relations'' (p. 352). The inclusion of social relations—including loss of life from famine, labor migration to cities, conflict over remaining resources, and collapse of local economic activity—recognizes the far-reaching effects climate events and changes can have in tearing communities apart.

Southern Africa's vulnerability to climate variability has promoted a strong research agenda investigating the effects of potential change, particularly on food security, the agricultural sector, and disaster management. Anticipated changes by midcentury to regional climate patterns include average temperature increases of 1°C, greater drought frequency, a 10% decline in the total amount of rainfall, and changes to rainfall timing (Boko et al. 2007; Lobell et al. 2008). The resulting decreases in agricultural production threaten food security for rural and urban poor. Overall production of maize, a regional staple, is expected to decline roughly 30% by 2030 (Lobell et al. 2008). During El Niño droughts, maize production could drop 20%–50%—a loss equivalent to the amount needed to feed 15 million people for one year (Stige et al. 2006). Furthermore, synergism between stressors raises vulnerability levels. Case studies in KwaZulu-Natal and Zambia demonstrate that climatic stressors exacerbate the negative effects of HIV/AIDS, endemic poverty, trade liberalization, contemporary conservation initiatives, ineffective institutional structures and processes, and marginalization of women (O'Brien et al. 2009; Reid and Vogel 2006). Therefore, individuals, households, and policy makers must think about more than just climate change when considering options and responding to livelihood and food security threats.

Focusing in on southern Mozambique, predictions for increasing El Niño–Southern Oscillation (ENSO) strength and frequency—and thus bigger, more frequent, droughts—emerge for the next century. ENSO strongly affects annual and interannual rainfall variation. Historic climate record analyses link ENSO to two-thirds of droughts in this region, and climate scientists suspect ENSO as the likely cause of increasingly erratic precipitation timing and amounts since 1984 (Coelho and Littlejohn 2000). In addition to affecting both food and water supplies, ENSO-related droughts and changed climate patterns are part of a suite of risks including cyclones, flooding, and disease outbreaks expected to severely degrade living conditions in southern Mozambique over the next 20 years (IRIN 2009). Effects will vary due to different combinations of site specific social, economic, and environmental stressors. As in South Africa, Mozambique's national economic liberalization strategies generated additional vulnerabilities for rural Mozambican households (Eriksen and Silva 2009; O'Brien et al. 2009). During the 2002/03 droughts Limpopo Valley farmers supported household needs by increasing their participation in informal economic activities, but the way market policies worked in their communities left them vulnerable to longer-term risks as the drought worsened. Context also influences perceptions of vulnerability. Research with policy makers and Limpopo Valley farmers following the 2000 floods found that the parties disagreed about future climate risks and the consequences of proposed adaptation policies (Patt and Schröter 2008). Examining stakeholders' mental models of climate change during recommended dialog would provide the insight into important local climate and climate-related changes, contextual stressors, and perceptions of vulnerability and risk needed for policy implementation success.

3. Human–environmental interaction in Matutúine District

Matutúine District (5403 km^2) is part of Maputo Province and the southernmost district in Mozambique (Fig. 1). Table 1 provides demographic information for Madjadjane and Gala, two rural communities where we worked. Residents belong primarily to the Mazingiri Ronga ethnic group, 85% and 95% of Madjadjane and Gala respectively, and their occupation of Matutúine District dates back at least 500 years based on evidence from oral histories, archived documents, and archaeological materials (Bruton et al. 1980; Felgate 1982; Junod 1927). The local economy is based on a combination of swidden agriculture and foraging. Livelihood activities such as fishing, goat and cattle herding, mat and charcoal production, beekeeping, reserve work, and tourism supplement household resources and generate income. While many livelihood activities were historically gendered, both men and women currently farm, work at the reserve or in tourism, and produce mats, charcoal, and honey for market. Single women (either unmarried or whose husbands are elsewhere) fish and herd livestock if they lack older sons or other close male relatives. Experiential

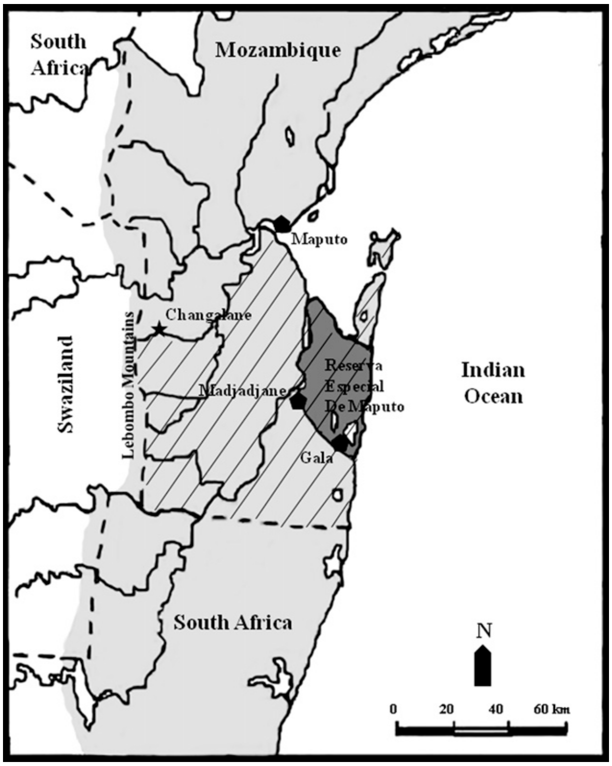

FIG. 1. Map of Matutúine District, Mozambique. Hatching indicates Matutúine District. Light gray signifies the Maputaland Centre of Endemism and the dark gray is the Reserva Especial de Maputo. Maputo, Madjadjane, and Gala are indicated with black pentagons. Changalane Weather Station is indicated with a black star.

TABLE 1. Community and interview respondent characteristics.

	Madjadjane	Gala
Community demographics		
Population	331	114
Number of households	64	24
Number of males	163	64
Number of females	168	50
Children (0–15 years)	124	46
Adults (16–70 years)	193	61
Elders (70^+ years)	14	7
Household earnings		
Average monthly earnings (2007)	1704 Mts.	886.4 Mts.
In USD at 2007 conversion rates	\$71.30	\$37.09
Number climate interviews	16	13
Women (70–100 years)	4	2
Mean time lived in community	71.3 yr	81 yr
Born in Gala	—	1
Born in Madjadjane	3	1
Born in Matutúine District	4	2
Men (70–100 yr)	1	2
Mean time lived in community	70 yr	33.5 yr
Born in Gala	—	—
Born in Madjadjane	1	—
Born in Matutúine District	1	2
Women (30–70 yr)	7	2
Mean time lived in community	37.9 yr	27.5 yr
Born in Gala	1	—
Born in Madjadjane	3	—
Born in Matutúine District	7	2
Men (30–70 yr)	4	7
Mean time lived in community	44.8 yr	29.7 yr
Born in Gala	1	3
Born in Madjadjane	3	—
Born in Matutúine District	4	4

learning and intergenerational transmission of ecological and cultural knowledge remains strong, despite large population losses in these communities during the Civil War (1986–92) because survival depends upon accessing a wide range of wild and domesticated resources through their mixed subsistence-based economy. Formal environmental knowledge enters Madjadjane and Gala through interactions with conservation organizations like the International Union for Conservation of Nature (IUCN), primary schools, visiting scientists, and the Reserva Especial de Maputo, a protected area adjacent to both communities.

A mosaic of grassland, wetland, woodland and thicket, swamp forest, and rare sand forest covers the sand dunes comprising Matutúine District's landscape. Freshwater and brackish lakes, along with the Maputo and Futí Rivers, contribute to ecosystem diversity and provide permanent water sources for human and nonhuman communities. Pans between the dunes hold water during wetter periods. This wide range of habitats contributes to the high biodiversity in the district. In fact, Matutúine District sits at the heart of the Maputaland Centre of Endemism, a 17 000 km^2 region containing 2500+ plant species including 225 endemic or near-endemic species and three endemic plant genera, 100 mammal species, and 470 bird species, including four species and 43 subspecies that are endemic or near endemic (Smith et al. 2008; van Wyk 1994). While only 19 km separate Madjadjane and Gala, the communities encompass a range of habitats available to residents for resource exploitation. Riverine woodlands, open woodland, and sand thicket and forest give Madjadjane, stretched along the Futí River, a predominantly woodland landscape. Gala's predominantly grassland landscape incorporates open and wooded savanna, hygrophilous grassland, sand forest–woodland mosaic, patches of swamp forest, and the shores of Lakes Piti and Ntiti (DEIBI 2000).

Figure 2 shows average monthly precipitation and temperature for Matutúine District. Hot, rainy summers prevail from October to April when the intertropical convergence zone (ICTZ), an equatorial low pressure system, moves south of the equator, releases latent heat, and interacts with sea surface temperatures. The movement of the ITCZ north of the equator from May to

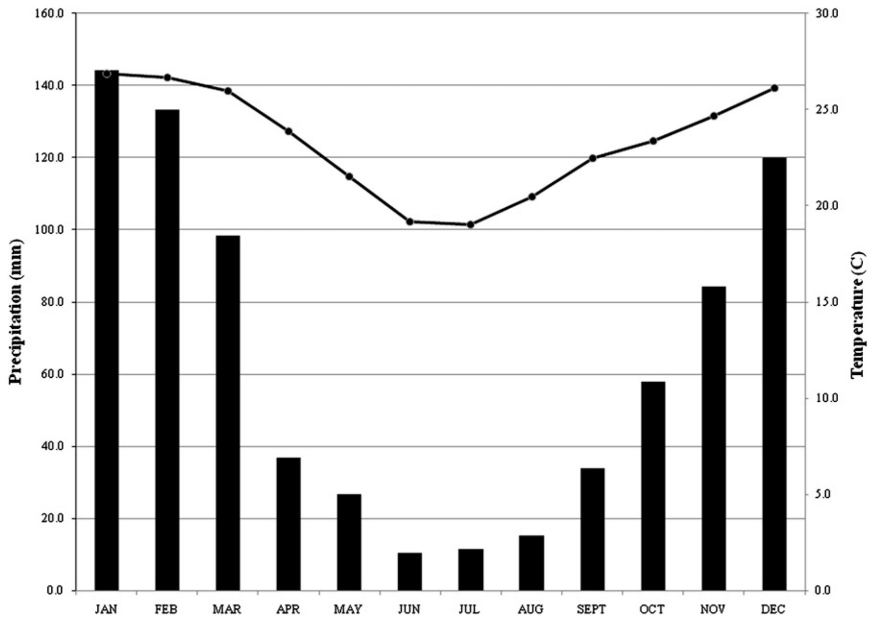

FIG. 2. Climate data for Changalane Weather Station, Mozambique. Monthly means are based on measurements taken from 1971–2000. The total annual average precipitation at Changalane is 767.19 mm. Black bars indicate mean monthly precipitation in millimeters, measured along the left *y* axis. The dotted line indicates mean monthly temperature, measured along the right *y* axis.

September coincides with Matutúine District's cooler, drier winter conditions. An ~18-yr oscillation, producing nine relatively dry years followed by nine relatively wet years, overlays the annual precipitation cycle. Tree ring analysis confirms the action of this oscillation over the past 600 years (Tyson et al. 2002). Rain generally falls heaviest along the coast (~1000 mm yr^{-1}) and on the eastern slopes of the Lebombo Mountains (~800 mm yr^{-1}). Madjadjane and Gala, located on the plains midway between the mountains and the coast, receive an average of 600 mm annually (Tello 1972). Temperature and relative humidity remain roughly constant across the district. Temperatures average 25.4°C during summer and 20.5°C during winter.

Climate significantly affects the socioecological system of Matutúine District. Average precipitation levels, particularly on the plains, hover around the transition from moist to arid savanna.[1] This precipitation ecotone likely contributes to high biodiversity and gives district residents access to diverse subsistence options. However, the timing and amount of rainfall also regulate vegetation production. Rainfall at the beginning of summer in October stimulates the annual growth of wild plants and signals people to clear fields and plant crops such as maize, cassava, peanut, and pumpkin. Additional rain over the months that follow determines actual production quality and quantity (Shorrocks 2007; Stige et al. 2006). Risks from interannual variation in precipitation to wild and domestic production ensure that most residents practice both swidden agriculture and foraging, but the dependence on vegetative production makes all local livelihood activities climate sensitive. Dry years are hard on rain-fed production, and drought wipes out crops completely. People use wild plants and purchase what food they can afford to make up the difference. However, during very bad drought or flood years both domestic and wild plant sources can fail, placing all livelihood activities at risk. At these times residents throughout Matutúine District may ask for help from family in South Africa and Maputo or migrate to these places for paid labor in the agricultural, mining, and service sectors.

4. Methods

a. Building and analyzing mental models of local climate change

Semi-structured interviews with 29 residents of Madjadjane and Gala were first conducted in Ronga, the local language, and translated into Portuguese for

[1] The savanna transition zone receives roughly 530–650 mm of precipitation annually. Arid, base-rich savannas receive less than 650 mm of rain while moist, nutrient-poor savannas receive more than 530 mm of rain (Rutherford and Westfall 2003).

analysis. Initially, we wanted to interview 10 men and women, aged 70^+, in each community because of their long interaction with the environment in this region. However, death, illness, and war-related outmigration made finding enough community elders to interview difficult. After asking for recommendations, interviewed elders suggested other male and female residents, aged 30 to 70, who they felt had relevant expertise and knowledge. Elders also recommended the chiefs of Madjadjane and Gala because they believed these men represent the community and have relevant expertise and knowledge. Table 1 summarizes community demographics, respondent characteristics by age, gender, birthplace, and the mean time a person had lived in the community where they were interviewed.

During interviews, respondents answered open-ended questions about local climate and climate-associated environmental changes, as well as the causes and consequences of climate change. Changes mentioned, such as ‘‘increasing temperatures’’ or ‘‘more conflict with elephants,’’ were coded as both quantitative and qualitative variables. Text analysis was used to assess how people connected climate changes and climate-associated environmental changes and to look at the interaction between local beliefs and change in terms of causes and consequences. Our use of an open-ended question structure likely led to more conservative results. No respondent was directed to comment on specific aspects of change, so more individuals could have observed a change than were recorded as having observed a change.

To construct the mental models of local climate change, we ran a two-step cluster analysis on all change-related and demographic variables. Two-step cluster analysis looks for optimal groupings of variables that best explain collected data, particularly when one has both continuous and categorical variables and is interested in exploring the relationships between them (Kaufman and Rousseeuw 2005). This analysis tool first identifies preclusters of related variables, which are then treated as single cases during the hierarchical clustering in the second step. Each cluster produced by the two-step analysis in our study represents a mental model of local climate change. An Akaike information criterion (AIC), AIC change (ΔAIC), and Akaike weight (w_i) were calculated for each set of clusters the two-step analysis produced. AIC is a rigorous, statistically solid method that focuses on the strength of the evidence to assess which cluster sets contain the simplest and most informative groupings of variables. Because it is not hypothesis driven, AIC conserves as much information as possible and intuitively chooses the optimal number of clusters (Burnham and Anderson 2001; Wagenmakers and Farrell 2004). Lower AIC values signify better variable clustering, while ΔAIC measures each cluster set relative to the best cluster set. The w_i value indicates the probability that the cluster set chosen is the best among all possible candidates.

b. Instrumental climate data analysis

After the interviews, we contacted the Instituto Nacional de Meteorologia (INAM) in Maputo, Mozambique, to obtain climate data for comparison. Changalane Weather Station, the closest to Madjadjane and Gala, provides climate forecasts for all inland areas in Matutúine District and has the longest uninterrupted dataset for this region. We obtained monthly temperature and precipitation data for 1963–2008, as daily temperature and precipitation data from this weather station were unavailable for some periods. However, Changalane receives slightly greater rainfall than Madjadjane and Gala because it lies in the foothills of the Lebombo Mountains rather than the midst of the savanna plains. This means that the instrumental measurements cannot account for microclimate heterogeneity at our field site. Recognizing the potential for climatic variation between the study communities and the weather station, we use Changalane data as a proxy for trend comparisons between instrumental measurements and informant perceptions. Temperature and precipitation means found in the site description (Fig. 2) and used for calculating SPI values are based on data for 1971–2000.

Prior to analysis, we reorganized monthly data from Changalane to reflect local conceptions of annual cycles so that comparisons could be made with interview data. While local conceptions of annual cycles may not necessarily reflect actual climate mechanisms, it was easier to rearrange the climate data in order to make comparisons. The year for local farmers begins in October, the traditional start of the growing season when the rains arrive, rather than January, the middle of the growing season. In our analysis, year 1963/64 begins October 1963 and ends September 1964. Summer lasts from October to April, winter lasts from May to September, and the early growing season months are October, November, and December.

We calculated average annual temperatures for summer and winter, generated a scatterplot of the values, and added a best-fit line to look at overall temperature trends for 1963–2008. We then ran a simple linear regression to determine if significant changes in temperature had occurred. A similar analysis was conducted for temperatures in the early growing season months.

Although many authors use the convention of percent difference from average rainfall for comparisons, we thought the potential rainfall disparity between our study communities and Changalane Weather Station necessitated an approach focused on relative wet and dry conditions. The Standard Precipitation Index (SPI) provides a simple assessment of precipitation by comparing monthly, seasonal, or annual precipitation to the long-term average for that same time period (Guttman 1998; McKee et al. 1993). Index values of −1 to 1 signify normal climate conditions, values less than −1 relatively drier conditions, and values greater than 1 relatively wetter conditions. SPI comparisons correlate indirectly to livelihood needs in that minimal local water requirements are met under normal to wet conditions. The SPI is useful because it can be assessed and compared at different time scales, requires only one input variable (thereby reducing error), is spatially consistent, and provides information on precipitation deficit and expected drought frequency (Guttman 1998; McKee et al. 1993). As we anticipated site-specific descriptions during interviews, this level of specificity was acceptable for our interests in understanding overall regional precipitation trends. We calculated annual, seasonal, and early growing season SPI values and plotted the values as discrete bars.

The lack of daily precipitation data and dates for the start of the annual rains prevented analysis of potential changes to seasonal timing. In lieu of this data, we ran a Pearson's correlation test on temperature and precipitation data for October, November, and December to determine if any significant relationship existed between the two variables.

5. Analyzing mental models of local climate change

The two-step cluster analysis revealed three optimal clusters of change variables (Table 2). This grouping has an AIC value of 552.597 (ΔAIC = 0, w_i = 0.96), and each cluster represents a mental model of local climate change. AIC analysis found community more significant than gender, although both are key variables. Figure 3 shows the models represented by each cluster of variables. Model 1 represents all 16 informants from Madjadjane and one informant from Gala, model 2 represents the remaining 12 informants from Gala, and model 3 (not shown) combines models 1 and 2. Further details about the models depicted in Fig. 3 are woven into the analysis below.

TABLE 2. Two-step clustering results with Akaike information criterion (AIC) values.

Number of clusters	AIC	ΔAIC	w_i
1	634.125	81.528	1.91×10^{-18}
2	560.432	7.835	0.02
3	552.597	0	0.96
4	560.336	7.739	0.02
5	572.186	19.589	5.36×10^{-18}

a. Ground-truthing climate change: Comparing mental models to instrumental measurements

To ground-truth regional climate change data and explore community experiences of change, we compared instrumental measurements to interview responses concerning observed climate changes. All respondents noted rising temperatures. Figure 4 shows significant temperature increases at Changalane Station between 1963 and 2008. Summer temperatures have warmed an average 1.4°C, while winter temperatures have warmed an average 1°C (Fig. 4a). Temperatures in the early growing season months have also risen significantly over this 45-yr period (Fig. 4b). The average temperature rose 1.7°, 2.1°, and 1.1°C in October, November, and December, respectively. People observed that the heat killed crops, grass, trees, and other plants through desiccation. Some linked the temperature increases to precipitation declines and stated that higher temperatures cause droughts. "Now it does not rain. It is all dry. In the past it rained a lot. The heat is not the same, now it gets very hot. A lot of heat causes drought" [female farmer, Gala].

Everyone interviewed also recognized that they are in the midst of a short-term drought/dry period. The annual SPI plot (Fig. 5a) shows drier years beginning 2003/04 and ending with a drier than normal period in 2007/08. Roughly 71% of all respondents mentioned that over the long term, the timing of the rains has become more erratic and that precipitation has declined. A Madjadjane farmer, born and raised in Gala, said people generally expect big floods every 10–15 years, but that the rains have become less predictable since 1980. His 100-year-old neighbor, also a farmer, believed the current drought to be just a part of the regular cycle of wet and dry periods. Although the elderly Madjadjane farmer did not mention the change to the expected long-term rainfall pattern, her observation highlighted the local recognition of a long-term rainfall oscillation. As expected, most annual SPI values for 1963–2008 fall within the normal range. However, beginning in 1983/84 the oscillation extremes appear to increase and the drier periods last longer. The plot of seasonal SPI, Fig. 5b, also demonstrates this change in the long-term precipitation cycle. Figure 5c, depicting early growing season SPI, displays a weaker signature for long-term change. Since 2000/01 October rainfall has been low in comparison to November's rain.

As model 2 shows, only Gala residents talked specifically about altered timing of seasons, particularly focusing on when the rains are supposed to arrive versus when they actually arrive. "Now we don't always know when the rains will start. The rains should start in October. And if it rains well, people will begin planting their fields"

Model 1: Madjadjane

Climate Changes:
- Short-term drought
- Over the long-term, the timing of the rains is erratic and there is less rain overall
- Temperatures are increasing

Environmental Changes:
- Crop production has declined
- Total way of life has changed
- Increased elephant raiding of crops
- Forests are smaller
- Wild fruit production has declined
- Less water in nearby rivers and wells
- Health problems/disease has increased
- Forests are bigger
- Population has increased
- New plants have appeared
- Agricultural pest appeared after 2000 floods

Respondent Characteristics:
- Madjadjane resident
- Lived in community on average 52.2 years
- Average age is 62.9 years
- Predominantly female (70.6%)
- Born in Madjadjane (58.8%), Gala (17.6%), Matutúine District (100%)

Model 2: Gala

Climate Changes:
- Short-term drought
- Over the long-term, the timing of the rains is erratic and there is less rain overall
- Temperatures are increasing
- Seasonal timing has changed

Environmental Changes:
- Crop production has declined
- Total way of life has changed
- Increased elephant raiding of crops
- Forests are smaller
- Wild fruit production has declined
- Fewer cattle
- Wildfires more common
- Population has decreased
- Fewer wild animals present

Respondent Characteristics:
- Gala resident
- Lived in community on average 33.5 years
- Average age is 59.3 years
- Predominantly male (75%)
- Born in Gala (25%), Madjadjane (8.3%), Matutúine District (75%)

FIG. 3. Local climate change models for Matutúine District, Mozambique.

[farmer-chief, Gala]. Bivariate correlation analysis of temperature and precipitation produced a Pearson's value of −0.481 ($p < 0.01$) for October and −0.361 ($p < 0.05$) for December. No significant correlation was found for these variables in the November data. The combined temperature and precipitation results for the early growing season suggest a weak, but not significant, trend toward a shift in the beginning of summer from October to November. The best evidence for changes to the timing of seasons comes from local rainfall observations of drier Octobers and wetter Novembers compared to growing season SPI values (Fig. 5c). This suggests that for locals, precipitation timing is more important than temperature in signaling season timing.

b. *Differences between mental models of local climate change*

Residents attribute a wide range of environmental changes to climate change, and significant differences exist between models. Of the cases included in model 1, 41.1% observed no climate-associated environmental change and instead attributed local environmental changes to the Civil War or its repercussions. Remaining differences between models stem from observations mentioned by only one or two individuals in each community.

Changes specific to model 1, observed by 58.9% of residents, include decreased river flow and groundwater, increased health problems, growing forested areas, more people in the community, the presence of new plants, and an invasive agricultural pest. Water availability is related to both agriculture and health. "Now it does not rain. Before people did not buy food. They ate vegetables grown at home, but now they do not" [female farmer, Madjadjane]. The chief of Madjadjane, in consultation with the community elders, told people to move their homes and fields closer to the Futí River in 2002/03 because of the drought. The chief explained that normally people do not cultivate directly adjacent to the river because of wildlife conflict and flooding issues, but during drought and drier periods water for crops can be found adjacent to the river. Women spend less time collecting household water when they live closer to a reliable water

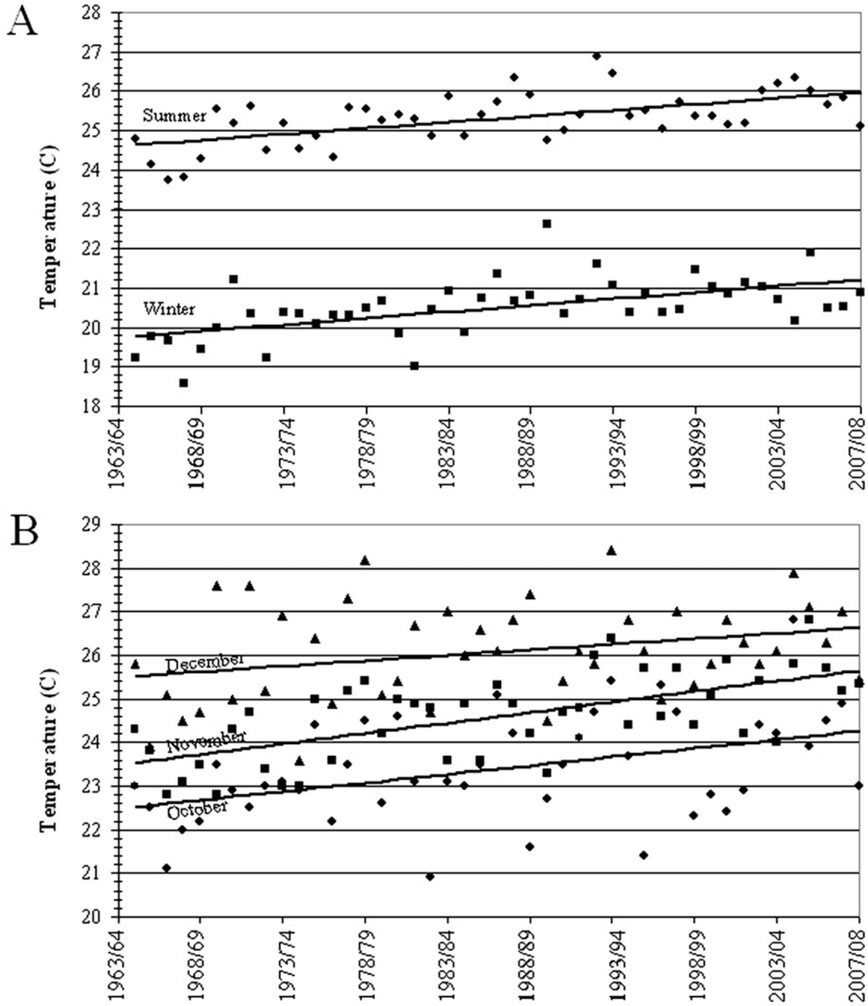

FIG. 4. Average temperatures for Changalane Weather Station, Mozambique 1964–2008. Years are found on the x axis. (a) Mean seasonal temperatures show (top) a 1.4°C increase for summer (diamonds; $y = 0.0305x + 24.6$, $R^2 = 0.351$, $p < 0.000$) and (bottom) a 1°C increase for winter (squares; $y = 0.0323x + 19.8$, $R^2 = 0.322$, $p < 0.000$). (b) Mean temperatures for the early growing season show a 1.7°C increase for October (diamonds; $y = 0.0397x + 22.5$, $R^2 = 0.18$, $p < 0.004$), a 2.1°C increase for November (squares; $y = 0.0482x + 24.6$, $R^2 = 0.403$, $p < 0.000$), and a 1.1°C increase for December (triangles; $y = 0.0252x + 25.5$, $R^2 = 0.086$, $p < 0.051$).

supply like the river, as many of the wells dug by the government and aid agencies dry up during the winter and remain dry during summer droughts. Yet river water consumption contributes to increased rates of diarrhea, dysentery, and water-borne parasites (T. Mutombene 2009, personal communication). An elder female Gala resident and Madjadjane's chief both linked poor health to hunger from lower food production. The combination of drought and wildlife conflict has made many hesitant to invest the time and effort needed to clear large areas for cultivation. Two residents reporting forest growth in Madjadjane believe the increases are due to fewer people clearing fields for agriculture. One woman mentioned population increases but did not explain why she believed they were connected to climate. Another female farmer in Madjadjane observed that flooding in 2000, associated with Cyclone Eline, made different plants grow and brought in a type of ant that destroyed maize and cassava plants by eating the leaves.

Environmental changes specific to model 2 included smaller forested areas, fewer cattle, increased wildfire frequency, fewer people, and fewer wild animals. Gala residents attribute reduction in forest size to flood destruction and increased wildfires. "At the height of the floods [2000], some trees died. The floods destroyed a lot of trees" [male farmer-builder, Gala]. "The forest is devastated by uncontrolled burns" [male farmer, Gala]. Gala's predominantly grassland habitat provides prime

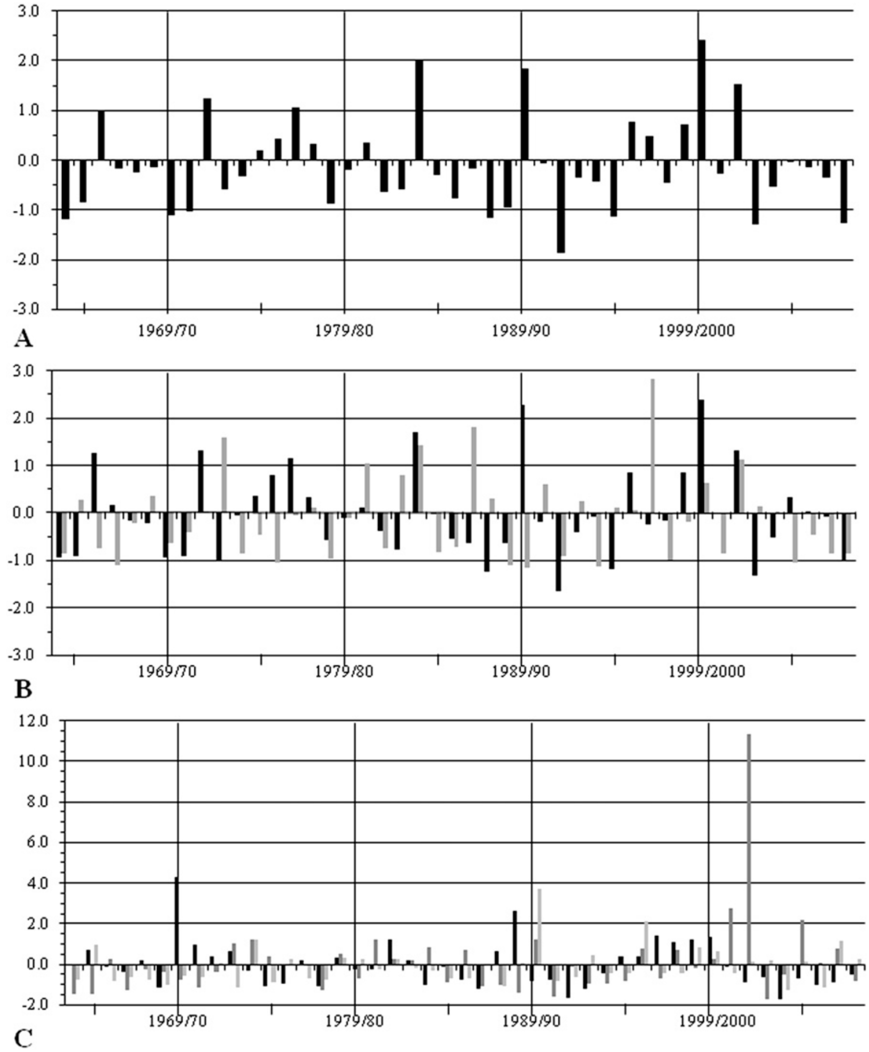

FIG. 5. Standard Precipitation Index (SPI) data for Changalane Weather Station, Mozambique 1963–2008. SPI values are found on the *y* axis and years on the *x* axis. Values −1 to 1 are considered normal, above 1 indicate wet to flooded conditions, and below −1 indicate dry to drought conditions. (a) Annual SPI values; (b) seasonal SPI values where winter is a gray bar and summer a black bar; (c) SPI values for the early growing season months: October (black bar), November, (dark gray bar), and December (light gray bar).

fuel for wildfires, and wildfire risks increase during drought and dry periods when vegetation dries out. The ongoing drought has made cattle replacement extremely difficult, even if residents were financially able to replace lost herds. ''The cattle did not go hungry in the past as there was rain—no problems with drought'' [male farmer-herder, Gala]. Herders move cattle regularly to take advantage of good forage. Without rain, the grasses cannot regrow quickly or extensively following grazing. Another herder explained, ''During droughts, many things die for lack of water including the grasses. It is a very dangerous time for cattle. They become thin.'' This lack of forage also affects wild animal populations. Finally, Gala's chief connected population declines to Cyclone Eline flooding in 2000. Thirty families returned to Gala between the end of the Civil War in 1992 and Cyclone Eline, but five families left for South Africa after the floods.

c. *Locally important environmental changes shared by communities*

While importance varies, men and women in both communities spoke of declining crop and wild fruit production, and increased crop raiding by elephants. ''In the past it rained. They cultivated and ate. But now fields are not cultivated because of the animals and the lack of rain'' [female farmer, Gala]. Historically, all the food consumed within the household was harvested from family swidden plots or the bush. Drier Octobers affect the quality and quantity of crop and wild fruit production by delaying planting and blossoming. The decline in crop production can also be tied to decreased crop diversity. ‘‘People grew more maize and timbaweni [*Vigna unguiculata*] because there was more rain. There are certain crops people don't grow because there isn't enough rain. We have the seeds, but we don't grow them'' [female farmer, Madjadjane]. A male farmer in Madjadjane mentioned that long-term drought weakens fruit trees, leaving them open to insect infestation and eventually death.

Residents face further risk from crop raiding and sharing of wild resources during dry and drought periods. Drought-induced declines in wild grass quality have been shown to trigger crop raiding by elephants (Osborn 2004). Additionally, elephants and humans eat many of the same wild fruits found in Matutúine District (Shaffer 2005). Wildlife conflict is a perennial problem in the study communities. While many animal species raid fields and consume wild fruits, residents consider elephants to be the worst offenders. Elephants eat the crops and wild fruits, and destroy wild fruit trees by breaking branches or pulling the tree up. Local farmers may hunt bush pigs (*Potamochoerus larvatus*) that raid their fields. However, residents rely on the adjacent reserve to chase elephants back behind electrified fences as it is illegal to hunt elephants. Only when particular animals repeatedly bypass the fence to raid crops and harass farmers are they destroyed and the meat shared out with the community. Interestingly, three of the four farmers, all women, observing increased elephant activity perceived only short-term drought—corroborating Osborn's (2004) observations in Zimbabwe.

Both models reflect perceived changes to the traditional Ronga way of life. Our fieldwork revealed that changes to food production and rain ceremonies are likely sources of this view. Swidden agriculture and wild food foraging are not the only livelihood activities at risk from climate change. Further conversations revealed that drought and drier periods increase risks for other livelihood activities such as herding, mat and charcoal production, construction, and honey harvests by desiccating and killing the plants that these practices depend on. Competition with crocodiles (*Crocodylus niloticus*) for fish increases and disrupts fishing livelihoods when rivers and lakes dry up. In some cases, family members migrated to South Africa to earn money and buy food to send home.

d. *Local perceptions concerning causes*

Our final interview question about the consequences and causes of climate change revisited concerns about the transformation of local culture and disruption of residents' way of life. Respondents (89%) believe they face famine and eventually death because of the long-term changes to expected precipitation patterns. All of the elders had personal stories of past droughts where children starved and family members died from hunger. Three people (11%) stated that ‘‘only God knows'' what will happen. Residents received government and international food assistance during the 1992 droughts and the occasional gift from religious organizations, but emphasized they cannot depend on outside aid. As several different individuals explained, much of the aid is used by urban populations in the capital and what little makes it out to rural areas goes to residents of bigger towns first because the ‘‘big trucks do not travel out into the bush.'' Therefore, local residents continue to rely on their traditional livelihood practices, migratory labor, and accumulation of new knowledge and skills to survive. If climate conditions alter to the point where these practices can no longer continue, famine, cultural disintegration, and death are possible.

Two residents cited global climate change as the reason for rising temperatures and unpredictable rainfall. These men interact frequently with aid agency staff and government workers both in the district and the capital, thereby giving them access to outside educational resources. Three people blamed God and conflict between neighbors, or stated they really did not know why. The majority (81%) in both communities blamed climate changes on a lack of rain ceremonies or improper rain ceremonies. Their response revealed the integration of local climate knowledge into the Ronga worldview of culture and community management.

Rain ceremonies are held at the end of winter in August or September, and in midsummer, early to mid-February, at the same time as the canhu (*Schlerocarya birrea*) festival. The purpose of these ceremonies is to ask the chiefly ancestors to intercede with God for rain and to thank the ancestors for the help that they have already given. Events surrounding Mozambique's Civil War (1975–92) and subsequent nation building altered four key aspects of rain ceremonies in Matutúine District during the timespan of our climate dataset. During Mozambique's Civil War, no ceremonies were held. The national government forbade traditional religious practices as part of their modernization efforts, and in many cases it was too dangerous for the community to gather anyway. When the war was over, people returned to Matutúine District and reestablished the rain and canhu ceremonies. However, in some places the old chief had been killed and the chief's sons were killed, too young, or did not wish to return to rural Mozambique. As a result, the new chief was not of the right lineage and therefore did not have the right to call on the ancestors for help. During the war, both FRELIMO and RENAMO[2] commandeered local cattle herds to feed troops while they were stationed in the district. Poverty and reduced fodder quality due to drought and dry conditions limited herd replacement after the war. Ronga rain ceremonies require the ritual sacrifice of a bull, so proper ceremonies could not be conducted following the war. Finally, opportunities and culture outside Matutúine District continue to influence the outlooks of younger community members. As one elderly woman explained, the ancestors were first angered by a lack of ceremonies and now are angered by the lack of chief of the correct lineage, a proper sacrifice, and the attitudes of the younger generation that do not take the ceremonies seriously. Therefore, the ancestors will no longer help their children to survive and prosper.

6. Why analyze mental models of local climate change?

Using local perceptions and observations to ground-truth regional models helps verify the extent of climate change, identifies locally important factors of change, and offers insight into the experience of living under changing conditions. In our study, we found that local residents recognize the long-term precipitation oscillation described by Tyson et al. (2002), and that some noted that this expected pattern became unpredictable in the 1980s, as Coelho and Littlejohn (2000) report. Residents confirmed a trend of temperature increases and suggested that first summer rains, initiating the growing season, are beginning later. These observations were made in the context of livelihood activities where residents use their knowledge of expected climate patterns to make decisions about household production. Their perceptions of increasingly erratic rainfall patterns reinforce the idea that climate change severely compromises the abilities of individuals and communities to sustain themselves as they have historically. The mental model results paralleled measured climate parameters despite potential influencing factors such as interviews occurring during a drought and people tending to remember the past as better than the present. Thus, results also demonstrate the reliability of people's climate perceptions.

[2] FRELIMO (Frente de Libertação de Moçambique) and RENAMO (Resistência Nacional Moçambicana) originated as political liberation movements during the War for Independence that ended in 1975 and fought for control of the government during the Civil War. Today, both act as political parties within the Mozambican government.

While residents emphasized social changes, their observations and perceptions also touch on local ecological patterns and processes and reveal connections between parameters of change not apparent in regional models. Residents' mental models show how reductions in household food production predicted by regional models result from a combination of delayed clearing and planting of fields, delayed blooming of wild fruit trees, groundwater and river flow losses, low quality forage for livestock and wildlife, increased crop raiding by elephants, invasive species, and lost labor capacity stemming from out-migration, hunger, and disease. Household production is further stressed by ripple effects in reduced honey harvests from delayed and reduced blossoming, destruction of useful trees and livestock forage by increasingly frequent wildfires, and growing competition with crocodiles for fish as the rivers and lakes dry up. Discussions surrounding community rain ceremonies revealed the importance of historical context and the indirect effects of war on traditional cultural practices, local economic activity, and long-term vulnerability to climate change. Local residents believe their entire way of life is changing, and the range of ecological, social, and economic disruptions engendered by and interacting with climatic stressors supports this perception of increased vulnerability.

Differences between community models arose during our analysis, and research on cross-cultural coping strategies offers one possible explanation. When solutions to an environmental problem are beyond the scope of individuals or communities to solve, people may manage their distress over a loss of control through wishful thinking or optimism bias (Nerb et al. 2008). People exhibiting optimism bias tend to perceive that positive events are more likely to happen to them and negative events more likely to happen to others. Those employing wishful thinking strategies underestimate or ignore problems. While we cannot rule out the possibility entirely, it seems suspicious that only Madjadjane residents reported no climate-induced environmental changes. Gala residents, who share family, history, and cultural ties with Madjadjane, should also report no changes if they were exhibiting optimism biases or practicing wishful thinking. Residents in both communities reported that climate and environmental changes had negative effects on livelihood activities and traditional cultural practices. We also found gender to be a significant factor. Livelihood activities, and therefore landscape use, are gendered, although current fluidity in practice participation makes gender difficult to disentangle from other possible explanations. Therefore, we put forward an explanation centered on the interaction between landscape variability and livelihood activities, recognizing the likely influence of gender.

We suggest that differences between communities in the perception of altered seasonal timing and climate-induced environmental changes result from differences in residents' day-to-day experience with predominant surroundings. Madjadjane's woodland habitats stretched along the Futí River are very different from the predominantly grassland environs surrounding Gala and the nearby lakes of Piti and Ntiti. Residents observe changes during daily interactions with their surroundings to harvest foods and materials necessary to the survival of their families and themselves. Furthermore, tree cover, access to water, and the spatial distribution of resources likely affect perceptions of change. Changes in tree-dominated vegetation along permanent waterways may be subtler and require large changes to become apparent. However, vegetation dieback and drying up of scratch wells or water holes in a drier grassland area might reinforce faster recognition of environmental changes driven by climate.

It is possible that Madjadjane's model represents a woodland climate change model and that Gala's model represents a grassland model for this district. Given that Matutúine District occupies almost 32% of the land area at the heart of the Maputaland Centre of Endemism, it would be worthwhile to compare Madjadjane's and Gala's mental models with climate change models produced in other woodland and grassland communities in the Centre to determine their relevancy at a larger scale. Southern African flora and fauna will be affected by predicted climate changes. Climate models suggest significant species range shifting from west to east throughout the entire region (Erasmus et al. 2002). In KwaZulu-Natal, South Africa, a combination of climate change and current land use threatens dune, sand, swamp, riverine, and lowland forests with significant area reduction and extinction (Eeley et al. 1999). These same forest types are found just north of KwaZulu-Natal in Matutúine District. Adding a more focused gender-livelihood component to this work would provide additional insight into specific gendered vulnerabilities and risks faced by Matutúine District's residents. Although land use practices and human population density differs on the Mozambican side of the border, mental models of local climate change from Matutúine District could improve the regional models used for planning purposes in the conservation, adaptation and sustainable livelihood sectors.

Analyzing mental models of local climate change offers insight into changes and connections that global and regional models cannot capture. None of the climate changes residents of this region have experienced between 1963 and 2008 seem exceptionally large or significant when read as numbers in a report. Yet when the rains fail, the success of local livelihood activities and functioning of ecological processes in Matutúine District deteriorates quickly. As one Gala fisherman stated, "Nothing can be done without rain." In this paper, we examined mental models to explore the predictions of regional models and improve understandings of how climate and environmental parameters interact to generate change at the local level. We discovered locally important changes that would likely not have appeared in regional models, yet remain important for local residents, and organizations working with communities, to respond to and plan for climate uncertainty.

Decision-making under uncertain environmental circumstances requires knowledge of past and present conditions to make the predictions needed for planning considerations. The predictions generated by regional climate models provide useful information to start thinking about intervention and adaptation. However, the models' coarse resolution averages effects across the landscape regardless of existing physical, ecological, and cultural diversity. Successful implementation of adaptation policies requires understanding how local communities perceive their vulnerabilities and respond to risks. We propose complementary analysis of mental models of local climate change as a way to access the more specific data required for the production of focused policy and decision-making. Site-specificity of the detailed observations used to generate a mental model cancels the averaging effect seen in regional models and establishes what locally important changes will need to be addressed for successful intervention and adaptation.

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