Chapter 7
Trajectories of Adaptation: A Retrospectus for Future Dynamics

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Abstract Sustainable adaptation to climate change needs to be assessed beyond the present time and location to include the way that current forms of adaptation might influence future response options. An analysis of past dynamics of adaptation, what we call "trajectories," might hold the key to understanding how the adaptive outcomes of past responses to climate stress constrain or open avenues to future adaptation. Adaptation research often focuses on particular actions, technologies, or institutions which may positively influence these relationships in order to build resilience and reduce vulnerability. However, relationships are complex and often behave in unexpected ways. There is no simple cause and effect, but rather actions are modified and transmitted through a web of linkages and feedbacks that are both physical and social. This complexity challenges our ability to predict the outcome of particular actions and there remain gaps in the understanding of system interactions that would permit a more accurate assessment of future development trajectories. The work presented here is an analysis of change in the climate vulnerability of dryland farmers in Northeast Brazil over four decades. The analytical framework, which links biophysical characteristics with a socio-economic context and indicators, permits an analysis that captures the dynamic relationship of adaptive capacities and consequent changes in vulnerability. The analysis of trajectories provides a foundation for future assumptions about human behavior and the relationship with the environment.

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7.1 Introduction

Adaptation describes an on-going and continuous process of interaction between human and natural systems. Natural system dynamics, such as global warming and climate change, introduce stressors into human system configurations which affect such human system outcomes as well-being, quality of life, or even survival. It is well-known that human system dynamics involving the introduction of technology and ecosystem also demands the alteration of natural system characteristics. Vulnerability describes the "success" of human system response to natural stressors and is assessed in terms of the magnitude of natural system variability, the sensitivity of the human systems to the impacts of this variability, and the capacity of the systems to absorb or recover from these impacts. Human system response outcomes which absorb natural stressor impacts and result in recovery which does not alter the "integrity" of the human system are said to indicate low levels of vulnerability and strong resilience (Folke 2006).

Vulnerability, however, is a shifting and not a static quality of human systems. As Walker et al. (Walker et al. 2004) have theorized, human systems "learn" in the sense that the very process of adaptation can result in changes in human response and in the nature of the natural system interaction, thus reducing vulnerability. On the other hand, systems which fail to learn may see their vulnerability increase. Furthermore, while responses to perceived or actual climatic changes may reduce current vulnerability, they may also reduce capacities to respond to future events (Barnett and O'Neill 2010; Fazey et al. 2011). This chapter seeks to identify this process of system learning as adaptation through time. We suggest here that the adaptation process reveals itself in past social-ecological system interactions and the understanding of past responses, particularly learning responses, provides an analogy for future adaptation. These changes (or not) in vulnerability through time, the outcome of natural and human system interaction, are characterized as "trajectories of adaptation," observable, even measurable, movements in the interaction of natural and human systems.

We assume here that such trajectories do not reflect random events, but the outcomes of specific efforts on the part of individuals, households, livelihood systems, and governments to adjust to variability in natural systems. The learning taking place over time may be manifest in the widespread adoption of new technological options, increased economic investment, a government policy set which neutralizes the impacts of natural system variability, or even improvements in governance and co-management strategies. Significant research is invested to identify the types of changes positively influencing levels of vulnerability and resilience (Conway and Schipper 2011; Gotham and Campanella 2011; Hisali et al. 2011; Smit and Wandel 2006). The lessons learned from this analysis of trajectories provide the inspiration for future strategies in adaptation to natural system change.

Trajectories trace the relationship of humans with the natural environment over time and they allow comparison of similar systems across space. This approach helps identify what is already working to reduce sensitivity, and what has made a positive difference in the lives of people. There is a need to recognize what has worked in a particular instance to reduce sensitivity, or, conversely, what may have aggravated sensitivity. Too often, however, vulnerability assessments are designed to identify deficiency rather than adequacy. This gap underscores the contribution of an analysis of trajectories. Additionally, adaptations need to be culturally and contextually sensitive, and there are few out-of-the-box adaptations which will work in all contexts. Critical knowledge for adaptation is contingent on the relevance to particular societies and cultures. Knowledge to help prepare for and respond to large-scale change needs to be situated within local contexts and understandings of society and the environment. Local and place-based characteristics of adaptation include unique cultural logics which guide human action and contribute to adaptation outcomes (Colombi and Smith 2012; Adger et al. 2012). Humans are able to evaluate information from the past, speculate about the future, and incorporate values and norms into decision-making processes. As a result, interventions in similar ecological systems may have dramatically different outcomes as a result of the way interventions are translated through cultural systems.

In analyzing particular trajectories we do not suggest the future in each location is determined by the past, but rather there is an inherent logic related to human response characteristics, both in the private sphere as well as in the public and policy spheres. Past behavior provides insight into the future, not because behaviors are deterministic, but because people tend to respond to challenges based on past experiences and within a range of choices determined by socio-political structures which are slow to change (Scheffer 2009). There is value in identifying common characteristics and analyzing patterns in systems across the globe. However, the ability to respond proactively to current challenges will need to draw from the rich and detailed diversity of experience and adaptation resident within populations around the world.

An understanding of the local nature of adaptation permits a more informed vision of possible futures. Similar to the need for climate models to be calibrated through backcasting, models used to forecast or develop scenarios of future social-ecological states need to be grounded in an empirical understanding of past behaviors and change. The ability to understand the trajectories of social–ecological systems, in the light of climate vulnerabilities, provides an indication of where a system is heading (Fazey et al. 2011) and where leverage points exist which may help guide the future trajectory. Unlike methods which capture only a snapshot of current vulnerability, methods incorporating past trajectories have a much stronger basis for developing plausible future scenarios (Thompson et al. 2012).

Our method to identify and analyze trajectories is straightforward. As described below, we have used time-series and cross-sectional data to identify natural system variability at the local level. Departing from the hypothesis that natural system variability has an impact on human systems, we have created impact measures sensitive to natural system variation, then analyzed this relationship over a period of four decades to identify locally the evidence for adaptation.

The objective of this chapter is to contribute to the growing literature focused on sustainable, long-term adaptations. To this end, we present an analytical framework designed to assess historical changes in the climate vulnerabilities of populations, in order to inform decisions about immediate and future adaptations. We illustrate the framework and the analytical contributions through a discussion of 40 years of public and private investments in drought adaptation in Northeast Brazil. In the section below we discuss the concept of trajectories and their potential contribution to adaptation studies. This is followed by a description of the research area, including a look at the environmental variability in the region and the importance of a focus on the local nature of adaptation. We then detail the way in which our model integrates biophysical indicators with socio-economic indicators to provide a perspective on the relationships between system components. We describe model outputs and how they contribute to the identification of trajectories of adaptation. Finally, we outline what we believe to be the primary contribution of a trajectory framework and how the results can contribute to a more informed, planned process of adaptation.

7.2 Trajectories of Adaptation

Vulnerabilities and adaptive responses can be documented as they change over time. The concept of trajectories provides a way to explore these changes in systems. We state that the trajectory of a system provides an invaluable perspective to prepare for current and future challenges. The analysis of trajectories grounds future assumptions about human behavior and the relationship with the environment. To predict plausible future directions, a basic understanding of past trajectories and change is required. The ability to predict the future location of a celestial body, for example, requires more than simply knowing its current location. It is necessary to describe the trajectory, to determine the forces acting on the body, and to understand how and where these forces will direct the body. The same perspective holds true for social–ecological systems. Trajectories inform an understanding of how contemporary situations of vulnerability and resilience arose. Importantly, they also provide a forward-looking view that anticipates the dynamic relationship between human actions and uncertain change. For example, in order provide insight into possible future scenarios and develop appropriate public investment strategies, methods, such as participatory timelines that capture relationships within social-ecological systems are used to elicit changes in vulnerability over time (Enfors et al. 2008).

The concept of trajectories implies three fundamental qualities related to planning and adaptation. First, trajectories describe pathways. In common discourse we often think about individuals, populations, and systems as following pathways.

The pathways may take on normative characteristics. For example, an individual can be on a path to betterment or self-destruction. Modernization proponents claim that investments and technology will put populations on a pathway to increased wealth, happiness, and consumption (e.g., Rostow 1990). The same concept is relevant for social–ecological systems. Vulnerability assessments frequently offer snapshots of a particular time and place, and, if not historical, are static and detached. The concept of pathways helps to conceptualize the continuity of systems through time and link past actions with current states of being.

Thus, trajectories also suggest historical depth. Contemporary literature on adaptation recognizes the importance of path dependency and legacies and how these historical artifacts contribute to the shaping of decision-making processes. Past decisions have the potential to limit our vision and response options. Pathways can be good or bad, but the human dimensions literature suggests that, to be able to respond to unexpected change, actors need to have access to a diversity of possible response options (Folke 2006). There is thus a forward-looking focus which seeks to understand how to break out of path dependencies and to reduce the influence of physical and social legacies. Historical depth also provides perspective on how a particular system came to be in its current state and helps identify current trajectories. It provides insight into why a particular population is vulnerable and the historical contingencies that created the context.

The third quality of a trajectory relates to inflection points. Inflection points mark locations of significant change, in which the directionality and curvature of a trajectory changes. They are the loci of change that provide insight into how trajectories are altered and they call attention to the set of factors necessary to induce change. Reflecting on the metaphor of a celestial body, analysis of inflection points can provide an empirical understanding of the forces at work at a given point responsible for controlling the direction of a system trajectory. If the slope of a particular trajectory represents the sensitivity of a system to climate perturbations over time, a constant slope indicates that sensitivity hasn't changed. However, at the point of inflection the slope changes and increases or decreases in sensitivity can be noted and tracked. This knowledge can illuminate the inner workings of a system and can be used to identify leverage points to initiate the desired change. Here, we concern ourselves with a focus on pathways and historical depth.

7.3 Adaptation on the Ground

The public and private adaptations occurring in the study region and elsewhere around the world are responses to perceived hazards and are intended to reduce vulnerability (Nelson et al. 2007). Here we consider vulnerability as the level of susceptibility of an analytical unit to a particular type of event in which the susceptibility is described by the characteristics of exposure, sensitivity, and response capacities (Adger 2006). Populations better adapted to drought demonstrate lower levels of vulnerability and, in our framework, changes in levels of sensitivity serve as proxies for changes in responses and levels of adaptation.

Ultimately, climate adaptation is constrained and facilitated by local (and finally the household level) parameters and phenomena. Sensitivity to climate perturbations is a function of the characteristics of the perturbations themselves, as well as social-ecological conditions and relationships. Northeast Brazil is well represented in the tropical drylands literature, particularly in relation to drought sensitivity. Much of the region falls within what is known as the *Polígono das Secas*, or Drought Polygon. The literature on the Drought Polygon frequently cites familiar indicators of biophysical characteristics including scarce and variable precipitation, high temperatures and solar radiation, high rates of evapotranspiration, and low soil fertility. On the social side, emphasis is directed towards levels of absolute poverty, measures of income inequality, out-migration, clientelism, and low education rates.

While perhaps representative in general, these characterizations gloss over the nuanced social-ecological heterogeneity across the landscape. Vulnerability is defined by the intersection of wider contextual variables with very local and specific characteristic sets through which stresses are propagated. Thus even within a given region, the experience of drought will vary. Trajectories are able to document the variety of relationships at regional and very local scales. The purpose of this chapter is not to detail this heterogeneity across Ceará, a state that is approximately 149,000 km^2. However, a brief description of the region, in particular the variability in rainfall and the availability of soil moisture, illustrates the claim that risk management strategies and adaptation must account for the local context.

Public responses to drought have a long history in Northeast Brazil. The vulnerability of the population came to public light during a severe regional drought in 1877–1879 in which hundreds of thousands of people died. In response, the federal government created an institution to “combat” drought. Its primary mandate was to increase water surface storage across the region through the construction of large and small dams. These water storage activities continue today. Public responses have passed through several phases since the first dams were built, all of which have approached the question of vulnerability from a technological perspective (Finan and Nelson 2001). These efforts include a focus on increasing agricultural productivity through the introduction of drought-tolerant crops, the development of large-scale irrigation projects, and attempts to modernize agriculture through increased mechanization. Yet, because the majority of the rural population did not have access to these programs, their impact was minimal (Frota and Aragão 1985).

Subsistence agriculture continues to figure prominently in the livelihood strategies of rural households. Beans and maize are the principal crops and production is based almost entirely on available rainfall. The highly variable nature of rainfall in the region translates into high-risk agriculture. Farmers have developed a number of household-specific adaptations to help distribute and manage risk over time and space. These strategies include planting a diversified set of bean and maize cultivars and planting across different fields in order to distribute exposure to weather events. One of the most critical decisions that a farmer makes is when to seed in the ground and there are numerous planting strategies to spread the risk of crop failure, including replanting.

The single rainy season can start as early as the beginning of December and can last into May. Most farmers will prepare their land in anticipation of the onset of the rainy season and wait to sow their fields until there is sufficient soil moisture to guarantee germination. However, if a farmer prepares too soon, labor is wasted because weeds and shrubs will take over the field. If he waits too long the best planting opportunities may be missed. Thus the decision of when and how to plant is a highly strategic and stressful decision and is the subject of constant speculation throughout the year.

In order to minimize the chance of total loss, few farmers plant their entire crop at once. This strategy is in response to the phenomenon called the *veranico*. A veranico is a short period (10–12 days) with little to no rain which can significantly impact agricultural productivity and often wipes out the first planting. It is common to have hard, plentiful rain, sufficient to force germination, which is then followed by a veranico. The challenge of a farmer is to assess not only the current soil moisture, but also the chance that this was an isolated rainfall. Thus, planting times are often staggered, either across fields or within an individual field. The following figures document the range of variation across space and through time for the 184 municípios in Ceará and highlight the decision-making context in which farmers must make critical agricultural decisions. The figures present different analytical lenses to explore rainfall and soil moisture variation as it relates to subsistence maize and bean production.

Figure 7.1a, b presents histograms which summarize the best planting date for beans in two municípios (Fig. 7.2a, b summarizes the best planting dates for maize), and which capture some of the risk management challenges faced by the farmer. The process to determine "the best planting date," depicted in the figures, is detailed in the section 7.4. The difference in the range of best planting dates of both crops is statistically significant, but, more importantly, it is significant from a risk management perspective. Maize farmers in Potiretama (Fig. 7.1a) and in Capistrano (Fig. 7.2a) have a much larger range of possible "best planting dates" than do subsistence producers in Chaval (Fig. 7.1b) and Barbalha (Fig. 7.2b). In Chaval, heavy rains in December have always been isolated rains. Even if the soil is sufficiently moist to guarantee germination, these rains are followed by veranicos. The Chaval farmers can rest assured that they don't need to prepare their fields in November or plant in December. The Potiretama farmer, however, has no such historical assurances. During the last 20 years their best planting dates have fallen across a range of 5 months. These differences have significant implications for individual farming strategies, but also for the other ways in which farmers seek to manage livelihood risks.

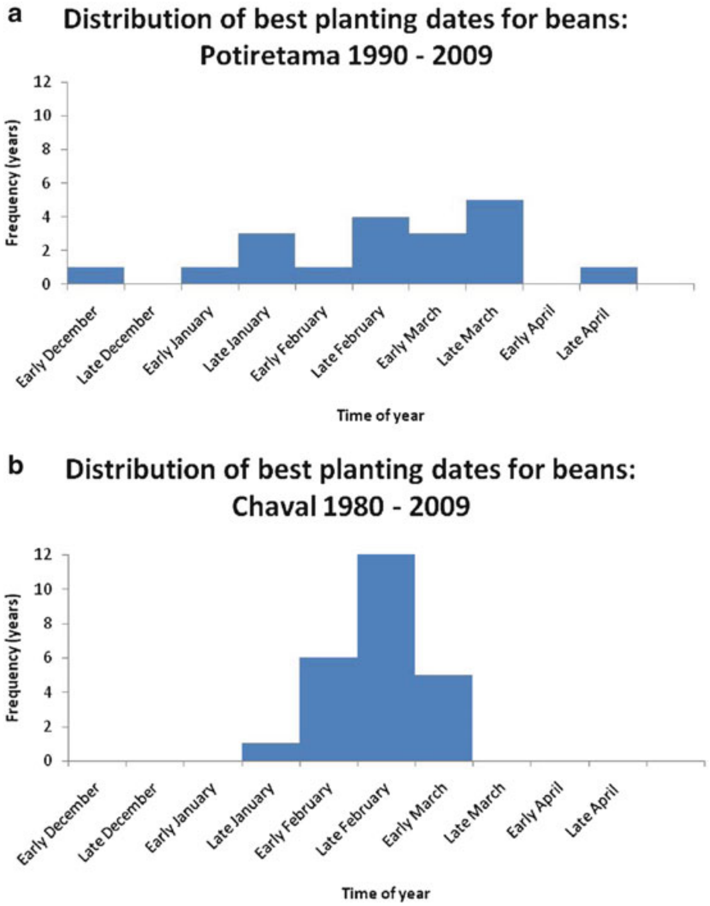

Fig. 7.1 (**a**) Soil moisture variation and bean productivity—Potiretama. (**b**) Soil moisture variation and bean productivity—Chaval

7.4 Trajectory Model

Two data sets were constructed in order to assess the relationship between rainfall and socio-economic indicators and describe the trajectories. The first documents the annual variation of soil moisture availability in relation to the needs of maize and beans. We gathered daily rainfall values across the state of Ceará for the years 1973–2009. The data was registered in a total of 193 gauges—although some gauges came online after 1973. Each gauge also has soil attribute data necessary to create a daily soil moisture model (Fig. 7.3).

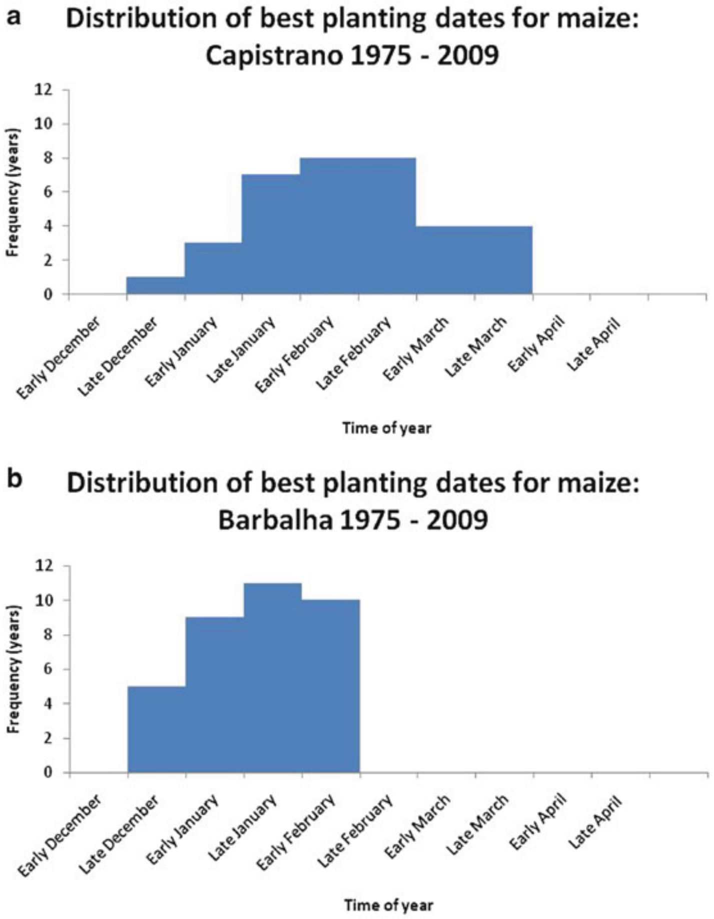

Fig. 7.2 (**a**) Soil moisture variation and maize productivity—Capistrano. (**b**) Soil moisture variation and maize productivity—Barbalha

$$\mathrm{US}_i = \mathrm{US}_{i-1} + \mathrm{Pr}_i + \mathrm{AC}_i + \mathrm{I}_i + \mathrm{ES}_i + \mathrm{ETR}_i + \mathrm{PP}_i \qquad (7.1)$$

where US_i is soil humidity at the end of day i; US_{i-1} is soil humidity at the end of the previous day, $i-1$; Pr_i is rainfall on day i; AC_i is capillary uptake for day i; I_i is irrigation for day i; ES_i is surface runoff for day i; ETR_i is real evapotranspiration for day i; and PP_i is deep percolation for day i.

This model was then used to estimate potential crop loss for each of the years in the data series for each of the rain gauges. The methodology for estimating crop productivity followed FAO guidelines in which relative yield reduction is related to the corresponding relative reduction in evapotranspiration (Allen et al. 1998; Doorenbos et al. 1979). Productivity loss is described based on the function of the evapotranspiration deficit during the phenological cycle of the crops in question

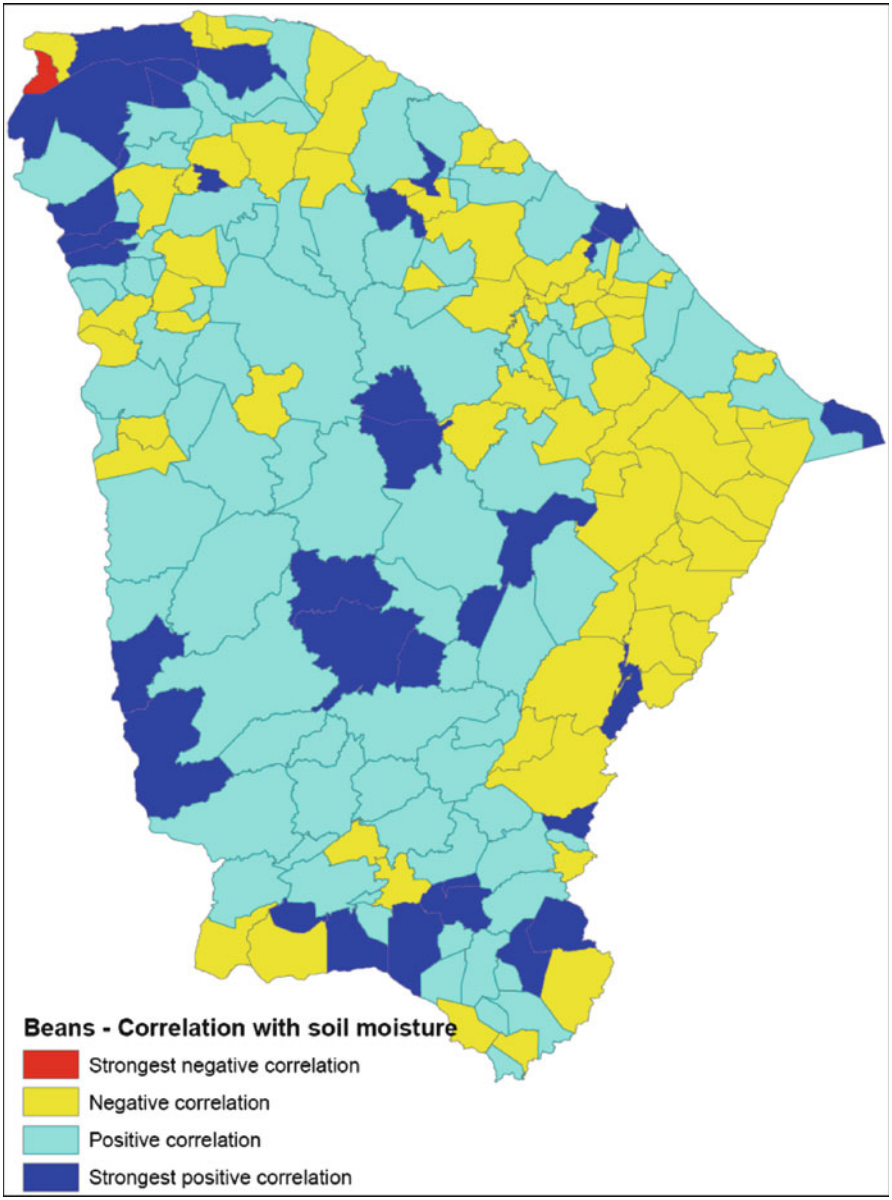

Fig. 7.3 Nature index β-values for predicting bean productivity

shown in (7.2) (Doorenbos et al. 1979). Model simulations were run for maize and beans from December 1st through April 30th. The models do not consider any type of soil management or other adaptations, but only potential evapotranspiration of the crop, the type of soil, and the timing and amount of rainfall. For each simulated day the model identified the maximum productivity for maize and beans. The model output does not represent actual productivity, but rather the estimated maximum productivity if an agriculturalist had planted on any given day. The model output is referred to as the Nature Index and represents the highest productivity for a given year. This number provided the best estimates in the regressions described below. The first maximum value in a year is what we refer to as "the best planting date" (see Figs. 7.1 and 7.2).

$$\left(1-\frac{Y_{\mathrm{a}}}{Y_{\mathrm{m}}}\right)=k_{\mathrm{y}}\left(1-\frac{\mathrm{ET}_{\mathrm{R}}}{\mathrm{ET}_{\mathrm{m}}}\right) \tag{7.2}$$

where Y_{m} and Y_{a} are the maximum and actual yields; ET_{m} and ET_{R} are the maximum and actual evapotranspiration; and k_{y} is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses.

The daily model results were then extrapolated to município level. The município level productivity was calculated using the weighted average of productivity calculated at each rain gauge (Prod_i) and the area of influence of each gauge (A_i), as described in (7.3). The area of influence was calculated using the Thiessen method.

$$\mathrm{Prod}_{\mathrm{m}}=\frac{\sum(A_i\mathrm{Prod}_i)}{A} \tag{7.3}$$

A second data set was developed that includes socioeconomic factors. These are publicly available, município-level time series data. The variables include actual production and productivity levels for maize and beans, município tax revenue, educational enrolment, infant mortality, emergency declarations, and livestock production. For the current analysis, a linear regression model used the nature index to predict each of the socioeconomic variables. The parsimonious model is designed to highlight relationships between each of the individual variables with the nature index. Two equations were used. Equation (7.4) explores variation in climate sensitivity across the state, and (7.5) is used to evaluate annual performance of each município. Outputs are discussed in the following section.

$$Y_{jt}=\alpha+\beta * f\left(\text{nature index}_{jt}\right)+\mu_j+\varepsilon_{jt} \tag{7.4}$$

where Y_{jt} is the socio-economic indicator in município j, year t; β is the expected change of the indicator for a one-unit change in the nature index, *ceteris paribus*; μ_j is the município-level fixed effects; and ε_{jt} is an error term.

$$Y_t=\alpha+\beta * f(\text{nature index}_t)+\varepsilon_t \tag{7.5}$$

where Y_t is the socio-economic indicator, year t; β is the expected change of the indicator for a one-unit change in the nature index, *ceteris paribus*; and ε_t is an error term.

7.5 Trajectories Revealed

Each of the indicators is hypothesized to be sensitive to changes in rainfall. For example, we hypothesize that bean productivity declines in years with a lower nature index and increases in years with a higher nature index. Where this is not the case, we anticipate human adaptations. Figure 7.3 provides an example of the relationship between the nature index and bean productivity. The map reports the β values at the munícipio level based on data from 1975 to 2009. The darkest munícipios are those with the strongest positive correlation between soil moisture variability and bean productivity. As we expect, productivity in these munícipios tends to follow the rain. However, this is not the case across the entire state. The lightest colored munícipios are those in which there is not a positive correlation and which are less sensitive to rainfall variation. In these munícipios the inter-annual variation of rainfall and soil moisture does not explain the variation in productivity. For people familiar with Ceará, the map makes intuitive sense. Many of the light colored munícipios overlap with the Jaguaribe River. The Jaguaribe was dammed early in the twentieth century and has since be the focus of intensive investment in irrigation infrastructure. Note that this map does not represent rainfall or soil moisture variability, but rather it represents the interaction of rainfall variability with farming technologies, strategies, and adaptations. The lighter munícipios are those in which sensitivity to climate variation has been reduced through human action.

Many vulnerability assessments demonstrate current levels of sensitivity, similar to the information documented in Fig. 7.3. While this knowledge is important and can be used to help develop priority areas for policy intervention, it provides little information in terms of pathways or historical depth. Here we argue that the addition of trajectories provides a value-added perspective for short- and long-term planning. For example, a munícipio that is currently vulnerable to drought, but which has had reduced vulnerability over the last four decades, has different needs compared to those of a munícipio that is also currently vulnerable but has become more vulnerable over the last 40 years. Figure 7.3 demonstrates the heterogeneity of current sensitivity across the state. However, due to our long experience with the region, we also know that sensitivity has changed differentially across the years of this study. Thus a munícipio showing very high sensitivity in 1975 may have lower levels of sensitivity in 2009. Although the rainfall patterns and the nature index may be similar in 1975 and 2009, the losses incurred in a particular munícipio may be significantly different depending on the adaptations implemented during this time period. Figure 7.3 is a static view of sensitivity and does not capture the dynamics. However, the ability to explain this type of change provides invaluable information to individuals responsible for investing public and private funds for adaptation and development.

Munícipio level trajectories provide insight into where and how vulnerability has changed during the last four decades. A linear regression model fits a line across each of the years of the study to describe the relationship of bean productivity with

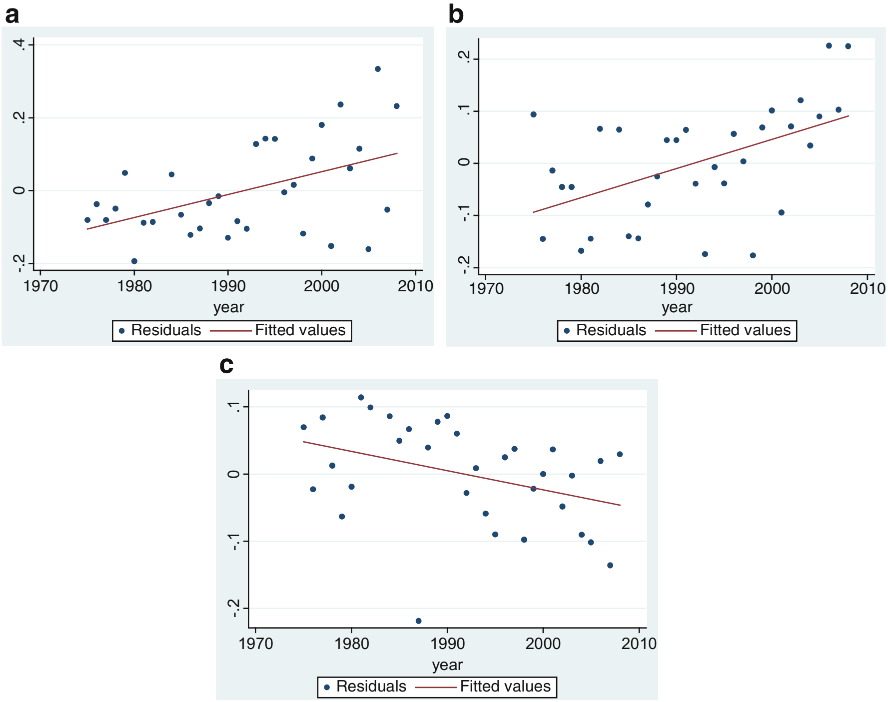

Fig. 7.4 (**a**) Acopiara error term in the nature index—bean productivity regression, plotted against time. (**b**) Baturite—error term in the nature index—bean productivity regression, plotted against time. (**c**) Frexerinha—error term in the nature index—bean productivity regression, plotted against time

the nature index in a single snapshot. Productivity describes the ratio of the production output (beans, kg) per unit of land (ha) and is therefore normalized over the years. In order to explore changes in the relationship throughout the study period, we plotted the error terms against time. This provides an indication of the strength of the relationship described by the regression line for each of the years. There are roughly three categories of relationships that emerge from this type of analysis: municípios in which the magnitude of the error term varied uniformly over time; those in which the magnitude decreased through time; and those in which it increased. The error term represents influences on bean productivity that are not explained by the nature index.

Figure 7.4a–c shows the output of the plots of the error terms against time for three municípios. Two of the municípios (Fig. 7.4a, b) demonstrate strong positive relationships between the error term and the passage of time ($p < 0.05$). We interpret these findings to suggest that, over time, the bean productivity in these two municípios has become less sensitive to the nature index. This indicates that other factors begin to contribute more significantly to the level of bean productivity and that climate sensitivity has decreased over the last several decades. In the third

Table 7.1 Parameter estimates for the relationship between error term and time

Figure	Coef.	Std. Error	t	$P > \|t\|$	95 % Conf. Interval	
Figure 7.4a: Acopiara	0.006	0.002	3.08	0.004	0.002	0.01
Figure 7.4b: Baturite	0.006	0.002	3.33	0.002	0.002	0.01
Figure 7.4c: Frecherinha	0.003	0.001	−2.24	0.032	−0.005	−0.000

município the relationship is reversed. There is a strong negative correlation ($p < 0.05$) between the error term and time. This finding suggests that bean productivity is increasingly explained by the nature index, which suggests that sensitivity to the environment is increasing over time (Table 7.1).

7.6 Conclusion

Our ability to prepare for the future, which is informed by an increased understanding of potential climate change and the recognition of the embedded quality of humans in nature, requires new types of information and analyses. Specifically, there is a need to understand better the vulnerability of a system in relation to variability and how the vulnerability changes through time. Vulnerability indicators need to be robust across outcomes. The weather events projected as a result of a changing climate within semi-arid regions will have a variety of impacts, which include food and economic security, morbidity, and others. Effective adaptation and development policy will be based on identifying determinants sensitive to policy changes and robust across the range of outcomes and which are proven to have had a positive impact in the local context. The data presented above focuses on only one outcome, but the analysis can be expanded to explore a suite of outcomes to assess better the trajectory of the system. This chapter presents an analytical framework for providing the type of information that policy makers will require. It also presents an empirical example of how to operationalize the framework.

Our findings demonstrate the importance of local context in determining vulnerability. All 184 municípios in Ceará are regulated by the same federal and state legislation, but the way in which policies and resources are operationalized varies, and there is significant heterogeneity in social indicators and institutions across the state. It is important to emphasize that the trajectories we explore are not measures of development. Indicators such as the Human Development Index already exist. Rather, trajectories are a measure of the sensitivity to rainfall variation, a natural characteristic of the region which continues to play an influential role in the lives of people. As suggested by work in Ethiopia, reducing sensitivity can positively influence poverty and growth rates (World Bank 2005). The analysis identifies municípios in the state which have been able to reduce sensitivity across a variety of socio-economic indicators. These municípios provide a source of experience which can inform and subsidize state-level policy. Although the preliminary analysis considers each variable in isolation, there is a need to identify how the determinants of vulnerability co-vary over time. Adaptive capacities are interrelated. Due to covariance, there are tradeoffs associated with adaptation decisions that make it impossible to maximize all adaptive capacities. Further analysis will seek to explain covariance over time in order to provide insight into the tradeoffs in investments and identify leverage points for maximizing investments.

A critical step in the analysis is the transition from the identification of patterns to the identification and explanation of the causes of changes in vulnerability. The analysis of secondary data provides a description of the spatial distribution of current vulnerability and how that vulnerability has changed throughout the decades. However, it doesn't serve to explain what underlies the trajectories of vulnerability. Future work will be dedicated to uncovering the particular sets of adaptations that changed the relationships between society and the environment in some of the municípios demonstrating the most compelling changes. The value of this on-the-ground work is that it will be possible to identify specific actions and activities which have led to reduced sensitivity or to increased sensitivity over 40 years.

This chapter has advanced the concept of "trajectories" as a way of interpreting past evidence of changes in adaptation as a possible analogue for future change under increasing natural system variability. The central message here is that changes in the relationships between natural and human systems occur at a local level and are influenced by local contextual factors. The time-series analysis also identifies points in time where trajectories are reconfigured, where "inflection" points caused either by the introduction of new technologies or the impact of new policies redirect the slope of the trajectories in some places. It is assumed that the understanding of these inflection points and their causes will help us to understand the available options under climate change scenarios for the Northeast. While these causes are beyond the scope of this chapter, the research agenda is clear.

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