

Adaptive Capacity and Social-Environmental Change: Theoretical and Operational Modeling of Smallholder Coffee Systems Response in Mesoamerican Pacific Rim

Hallie Eakin · Luis A. Bojórquez-Tapia ·
Rafael Monterde Diaz · Edwin Castellanos ·
Jeremy Haggar

Received: 1 December 2009 / Accepted: 10 December 2010 / Published online: 14 January 2011
© Springer Science+Business Media, LLC 2011

Abstract Communities who rely directly on the natural environment for their survival typically have developed risk management strategies to enable them to avoid dangerous thresholds of change to their livelihoods. Development policy appropriate for natural resource-based communities requires an understanding of the primary drivers of social-ecological change, the ways in which affected households autonomously respond to such drivers, and the appropriate avenues for intervention to reduce vulnerability. Coffee has been, and still remains, one of the most important commodities of the Mesoamerican region, and hundreds of thousands of smallholder households in the region are dependent in some way on the coffee industry for their livelihood stability. We used the Analytical Network Process to synthesize expert knowledge on the primary drivers of livelihood change in the region as well as the most common household strategies and

associated capacities necessary for effective response. The assessment identified both gradual systemic processes as well as specific environmental and market shocks as significant drivers of livelihood change across the region. Agronomic adjustments and new forms of social organization were among the more significant responses of farmers to these changes. The assessment indicates that public interventions in support of adaptation should focus on enhancing farmers' access to market and technical information and finance, as well as on increasing the viability of farmers' organizations and cooperatives.

Keywords Adaptation · Land use change · Tropical agriculture · Latin America · Livelihoods · Analytic network process

Introduction

Coffee has been and still remains one of the most important commodities of the Mesoamerican region. Guatemala, Mexico and Honduras are among the top ten largest exporters of Arabica coffee in the world, followed closely by Nicaragua, El Salvador and Costa Rica. According to FAO statistics, coffee exports account for as much as 25% of total export value in Honduras and Nicaragua (Table 1). Furthermore, hundreds of thousands of smallholder households in the region are dependent in some way on the coffee industry for their livelihood stability (Lewin and others 2004).

At the peak of the global coffee crisis in 2003 when world coffee prices collapsed to historic lows, there were some attempts to coordinate policy and interventions in the coffee sector across the region through international aid organizations and through policy initiatives of the

H. Eakin
School of Sustainability, Arizona State University, Tempe,
AZ, USA

L. A. Bojórquez-Tapia (✉)
Institute of Ecology, Universidad Nacional Autónoma de
México, Ap. Postal 70-275, 04510 Ciudad Universitaria,
DF, Mexico
e-mail: l_boj@yahoo.com

R. M. Diaz
Universidad Politécnica de Valenc, Valencia, Valencia, Spain

E. Castellanos
Centro de Estudios Ambientales, Universidad del Valle de
Guatemala, Guatemala City, Guatemala

J. Haggar
Centro de Agronomía Tropical para la Investigación y
Enseñanza, Managua, Nicaragua

Table 1 Coffee production volume and contribution to agricultural export value in selected Mesoamerican countries

Country	Production volume 2007/08 (60 kg bags × 1000) ^a	Value of green & roasted coffee exports as % of all agricultural product exports ^b
Mexico	4 150	2.4
Guatemala	4 100	25.0
Honduras	3 842	47.0
Costa Rica	1 791	9.9
Nicaragua	1 700	39.0
El Salvador	1 621	34.0

^a International Coffee Organization (www.ico.org)

^b FAOSTAT

International Coffee Organization. These initiatives resulted in a series of recommendations: among others, promoting crop and economic diversification in coffee producing regions (particularly in lower altitudes), reducing the volume of low-quality coffee entering national and international markets, and encouraging the participation of farmers in higher-return niche markets such as gourmet, fair trade and organic (International Coffee Organization 2001; IDB/USAID/WB 2002; International Coffee Council 2003; Lewin and others 2004).

These initiatives were important at the time and coffee prices have improved significantly since 2003. Nevertheless, the social and economic upheaval that characterized the crisis and the international response speaks to a growing need for coordinated regional assessments of rapidly changing social and environmental conditions. Such evaluations of the drivers and outcomes of regional change can help broaden the scope and integration of policy, not only in the context of a particular national setting, but also regionally. The need for integrated assessments to inform appropriate responses to social-ecological change at different scales is perhaps one of the greatest challenges of the twenty-first century (Hassan and others 2005).

Along with a wide variety of other such export commodities produced in the tropics—tea, rubber, bananas, cocoa, sugar cane—the market and supporting policy for coffee has historically been viewed primarily in industrial terms. Over the last two decades, however, thinking about the crop and coffee farmers has changed. Today coffee is not viewed simply an industrial commodity, but rather in more complex and even iconic terms. Coffee is now often associated with seemingly unrelated concepts such as tropical biodiversity, migrant bird habitats, the provision of other ecosystem services (e.g., carbon sequestration) as well as with indigenous cultural survival and small farmer empowerment. In other words, coffee is not simply a cash

crop, but rather emblematic of a complex coupled social-ecological system.

Viewing coffee in *systemic* rather than in sectoral or industrial terms provides significant challenges for policy. Policy interventions in coffee markets may or may not have direct implications for ecosystem services, rural poverty or participation of smallholder producers in national politics. The dynamics of globalization and increasingly integrated markets not only demand a broader vision of what might constitute a decision environment for any single small coffee-producing nation, but also a more integrated understanding of the sector and smallholder vulnerabilities (Eakin and others 2009).

In order to develop more informed scenarios of social, ecological and agricultural change, we argue that it is important to understand how farmers across the region are responding to diverse stressors, and what the implications of their responses may be for the region as a whole. The vulnerability of farm households and landscapes across the region are not only tied through their common dependence on the global coffee market, but also to intra-regional migration flows, trade in consumer goods fueled by coffee revenue, a shared history of socio-economic development, and collaboration in agricultural research and support programs. While understanding the local determinants of farm-level and ecosystem vulnerabilities is critical for national policy-making, it is also important to identify regional patterns in sensitivities and responses of farmers in order to anticipate the direction of livelihood and landscape change and potentially to develop regional-level policy interventions.

Identifying and conceptually ‘mapping-out’ drivers of social and ecological change has recently been recognized as an important if not a fundamental activity for sustainability planning at different scales (Petschel-Held and Lasco 2005). Nevertheless, there have been relatively few attempts to systematically document drivers of change in specific social-ecological systems for policy audiences, with the notable exception of the Millennium Ecosystem Assessment (Hassan and others 2005). The effort described here uses a multicriteria decision analysis framework and expert knowledge to systematically structure the assessment process in order not only to elucidate hypothesized cause-effect relationships, but also to emphasize the systemic nature of social-ecological change.

Our assessment of expert knowledge and regional experience suggests that there are general trends and patterns in the type of stressors farmers are facing, and there is also a basis for consensus concerning the types of farm-level and sector responses that appear most promising for achieving development objectives. Together these insights may provide valuable lessons for regional policy. Nevertheless the local geographic circumstances of production

vary significantly within each producing nation, requiring that any intervention is framed within the local contexts, responsive to specific needs.

In the section that follows, we provide a brief overview of the global circumstances that have introduced new uncertainties into the future of coffee farming in the Mesoamerican region. In the third section, we describe an exercise designed to synthesize the collective knowledge of a group of academic experts who are collaborating together in an assessment of farm-level vulnerability across the Mesoamerican region (Castellanos 2006). In the fourth section, we describe the results of the synthesis exercise. In the final sections we discuss the utility of our approach and conclude with a discussion of the potential lessons to be gleaned from this exercise for coffee sector and rural development policy in the broader region.

The Importance of Coffee in Mesoamerica

Coffee is a tree crop, and in Mesoamerica it is often grown as an under-story crop under managed forest shade. Topographically, the region is transected by a continual volcanic range, supporting tropical cloud forests at elevations of 900–2000 m where annual rainfall often exceeds 1000 mm with values as high as 5000 mm. It is on the steep slopes of the region's mountains that small-scale farm households have grown coffee for generations, many since the late nineteenth century. When exposed, the volcanic soils of this region are generally prone to erosion, particularly in the face of the relatively frequent torrential rainfall events associated with tropical storms and hurricanes.

When grown under managed forest cover, there is evidence that shade-grown coffee may enhance the retention of organic matter and slow erosion compared to alternative agricultural land uses (Richter 2000; Manson 2004; Pérez-Nieto and others 2005). Coffee farms with more complex vegetative cover have been shown to resist some of the most detrimental effects of heavy rainfall and associated landslides (Philpott and others 2008). In addition, unlike some alternative land uses (e.g., maize and livestock farming) shade-grown coffee production has been shown to counteract the negative impact of habitat fragmentation and biodiversity loss that are increasingly problematic in these mountainous areas (Pineda and Halfpeter 2004). While coffee is not without environmental impacts (particularly associated with washing and processing the coffee cherries), when grown with minimal chemical inputs and relatively complex vegetative cover it is considered a crop that could provide more ecological and social services than costs (Kessler and others 2007).

Yet smallholder coffee production is now threatened by complex processes of environmental and socioeconomic

change. Coffee prices plummeted as a result of change in the structure of international coffee markets and an increase in world supply in the last half of the 1990s (Ponte 2002). The collapse of the International Coffee Agreement in 1989 precipitated an increase in price volatility. Although prices have improved considerably since their lowest point in 2002–2003, the market remains volatile. While the global demand for coffee is steadily increasing, the constraints of the production cycle have made it difficult for farmers to meet this demand in a controlled fashion.

Domestically, many coffee-producing countries in Mesoamerica have undergone institutional restructuring resulting in a contraction in public support for agricultural services such as credit and inputs, and a reduction of state intervention in coffee commercialization, prices and marketing (Eakin and others 2006). These institutional changes coincided with a period of significant climatic variability. An unusual sequence of El Niño-Southern Oscillation events resulting in prolonged drought conditions, combined with the devastating impacts of Hurricanes Mitch (1998), Stan (2005) and most recently, Agatha (2010) severely stressed smallholder production. Climate change may threaten the long-term viability of coffee in Mesoamerica (Gay Garcia and others 2006; Baker and Haggard 2007; International Coffee Council 2009). Rising temperatures are expected to affect the productivity of Arabica coffee, and may also increase the prevalence of coffee pests such as the coffee berry borer (Gay Garcia and others 2006; International Coffee Council 2009). Droughts are also expected to become more common, and the presence of mist that provides substantial humidity in the montane cloud forests (where coffee is produced) is declining (Hulme and Sheard 1999). The frequency of severe hurricanes is also of a concern: there is some limited evidence that as ocean temperature warms, the Atlantic may support the development of more intense and destructive storms than in the past (IPCC 2007, pp 306–307).

In addition, the continued volatility of international prices is particularly challenging for producers in those countries that, for reasons of volume or quality of production, are price-takers in international markets. Without alternative sources of income and sustenance, these populations are highly susceptible to the complex social problems associated with rural poverty. The fragility of the coffee sector is also of concern for ecological reasons: There are few alternative crops that are as well-suited to the rugged terrain of the Mesoamerican mountain ranges, and which are as compatible with the cloud forest ecosystem of this region. Any large-scale conversion of coffee land to pasture, maize and bean production, sugar cane or even residences raises concerns over the potential for increased rates of soil degradation, further fragmentation of

forest cover and increased susceptibility to losses from landslides and torrential rainfall events.

Building the Model

In this project, we used the Analytical Network Process, a multicriteria modeling technique developed by Saaty (2001), to develop a representative model of the coupled socio-ecological system of the coffee sector in Mesoamerica. The goal was to capture the processes that are producing change in the system at different scales (drivers), and to the extent possible, the outcomes and feedbacks in the system associated with these drivers.

In general, a system is conceptualized in the ANP as a network of a set of components—or clusters—and elements within these clusters. The ANP permits the inclusion of dependence and feedbacks among elements of a system. It focuses on the use of pairwise comparisons in which relative preferences or differential degrees of importance of one element in relation to another can be quantitatively derived using a ratio scale. Once all the pertinent pairwise comparisons are completed, the results are analyzed mathematically to generate the importance weights for all the elements in the network (for details see Eakin and Bojórquez-Tapia 2008).

Expert Consultation

We convened an expert consultation workshop in March of 2008, to which a multidisciplinary group of experts with experience in working in the coffee sector were invited. These 15 experts had experience working with coffee farming in Costa Rica, Guatemala, Honduras, Nicaragua, El Salvador and Mexico. Together, they represented disciplinary expertise in rural sociology, agronomy, economics, agroecology, biology, geography, and anthropology. The experts were primarily academics, although several were also involved in civil society groups associated with rural development. An email survey to elicit the initial set of candidate variables (system drivers and farm-level characteristics) was completed by the participants prior to the workshop.

During the two-day workshop, the experts selected and defined an initial hierarchical structure of the primary drivers of change in the Mesoamerican coffee system, and, where their knowledge permitted, identified relations (loops, feedbacks) between drivers in order to create the basis for the subsequent network model. We considered “drivers” to be exogenous stressors on the Mesoamerican coffee system. In other words, these drivers were biophysical and socioeconomic/ political factors over which individual farm households have had relatively little direct

influence. We only incorporated in the model the relations between drivers over which there was no controversy or doubt among the participants.

As described in greater detail below, we considered an “adaptation” to be “the decision-making process and set of actions undertaken to maintain the capacity to deal with future change or perturbations to a social-ecological system without undergoing significant changes in function, structural identity, or feedbacks of that system while maintaining the option to develop” (Nelson and others 2007, p 397). All of the experts were professionally involved in documenting and evaluating the diverse ways that farm communities and households have responded to the exogenous drivers of change in the last decade. While concrete quantitative data of household responses at the regional level was not available at the time of the workshop to inform the process of model construction, each of the participants was involved in ongoing research with coffee farm households. This knowledge and experience was combined with prior published research on the coffee sector and on smallholder livelihood strategies (Bebbington 1999; Ellis 2000; Eakin and others 2006) to identify a list of plausible farm-level responses.

Finally, the experts recognized that in order for the modeling effort to be useful for informing policy, the model would need not only to describe stressors and adaptations, but also highlight possible areas of intervention to support the adaptation process. This policy objective was met through the identification the specific farm-level “capacities” that were thought to be necessary for farmers to engage in specific adaptations. A livelihood framework (Scoones 1998) was used to define the domain of capacities. As such, the experts characterized capacities in terms of categories of assets or “capitals” which the household either owned or directly controlled (e.g., land, family labor), or to which the household had access (e.g., transport, credit).

The degree of specificity used to describe each driver in the model (e.g., ‘rainfall unpredictability’ vs. the more general category “precipitation”) was based on the extent to which the experts could provide sufficient evidence to confidently associate a demonstrated change in some aspect of the system with a specific driver. If the experts were not able to define a specific relationship, but the driver was still considered to be important, a more general descriptor was used. In this case, for example, “rainfall unpredictability” was subsumed into the more general concept of “precipitation”. In linking drivers to adaptations, if the experts were unable to provide empirical evidence to connect an identified driver to a specific adaptation, the driver was reconsidered, and in many cases dropped.

Following the construction of the model (described in detail below and represented in Fig. 1), the experts

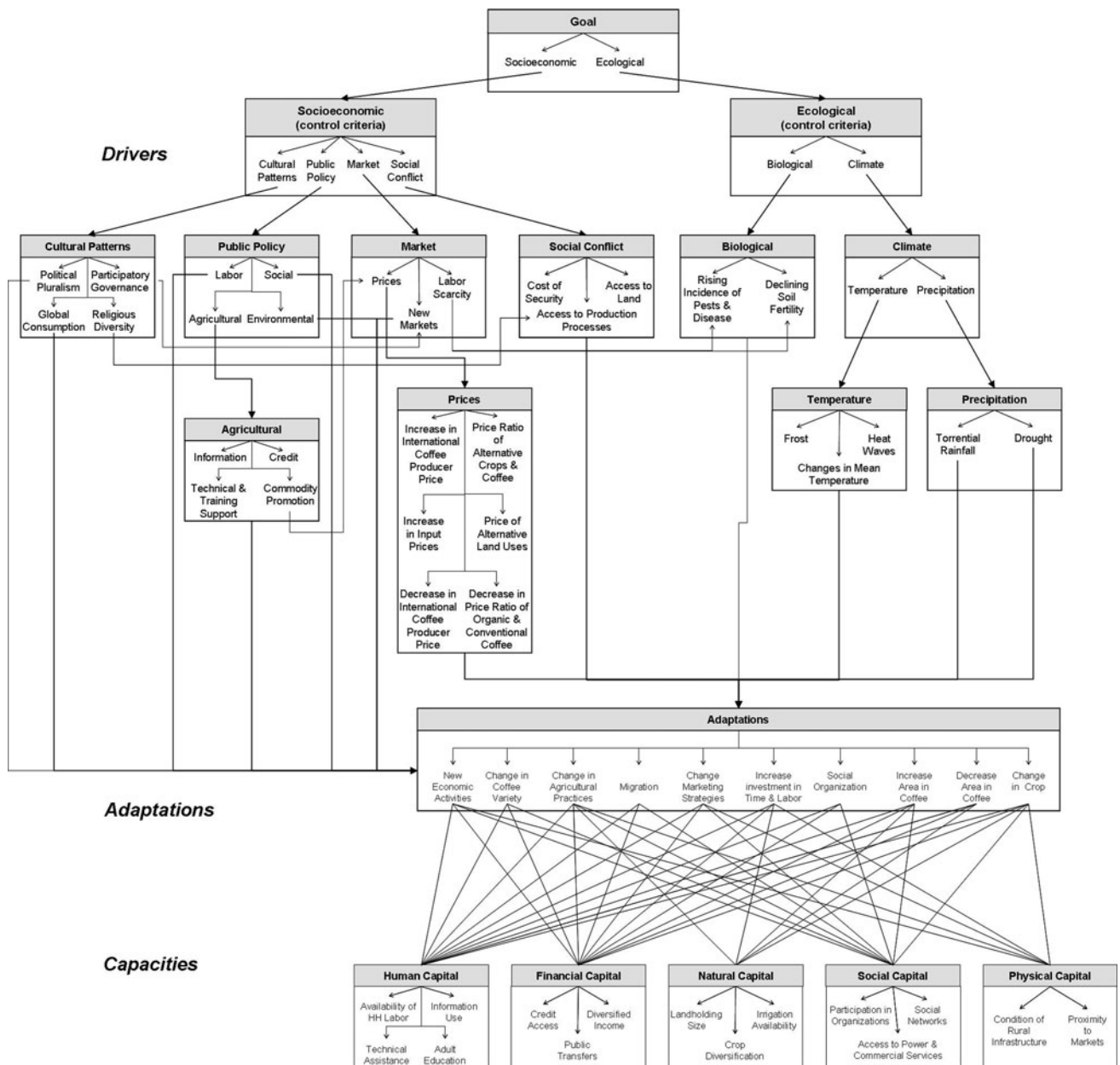


Fig. 1 Model structure of the SES-SCFM

assessed the relative importance of each driver using pairwise comparisons. Each pairwise comparison was discussed openly and collectively among the experts until an agreement was obtained. The discussion was not focused as much on which of two elements being compared was more important, but rather the degree of greater importance.

Operationally, the pairwise comparisons entailed the use of the so-called AHP’s fundamental scale to rate the relative importance among elements in the model. This scale involves a 1–9 numerical rating and corresponding verbal

judgment, where 1 represents equal importance and 9 indicates that the first criterion is extremely more important than the second one (see Eakin and Bojórquez-Tapia 2008). The rationale of comparisons among climatic drivers (see below) illustrates the thought-process involved in undertaking the pairwise comparisons. In this case, the question posed to the team of experts was “with respect to Climatic drivers: What is the importance of Precipitation relative to Temperature in relation to socio-economic change in Mesoamerica?” As shown below, the team of experts concluded that changes in patterns of precipitation were

moderately more important than temperature and thus the assigned numerical rating is 3.

This process trained the experts in the use of the ANP, improved the model's structure and performance, and reduced the inconsistencies in subsequent steps. Following the workshop, the model was refined and improved by means of an iterative process of consultation with the participants through emailed questionnaires and responses. As a result of this process, new information was introduced and some elements and relationships in the initial model were modified, using the literature on smallholder adaptation to global change as the main theoretical reference. Modifications to the model were submitted for approval to a sub-set of experts in successive consultations. This process also produced the list of adaptations. This list was categorized according to common classes of adaptive responses referred to in the theoretical and empirical literature (e.g., Siegel and Alwang 1999; Agrawal and Perrin 2008), and took into account empirical work of the experts in each of the represented countries.

An email survey to the expert group using the AHP/ANP verbal scale was used to formalize and prioritize the relationships between the identified drivers and adaptations, and between adaptations and a list of household capacities / assets that were considered important for engaging in such adaptations. By calculating the geometric mean of the pairwise comparisons implemented by each of the experts (Saaty 2001), the contributions of the individual experts were integrated into the final model. In the case of high inconsistencies in the pairwise comparisons, extra consultations were performed to ask the experts to refine and re-evaluate their assessments until the required level of consistency was achieved.

ANP Model Development

For greater clarity and precision, the ANP model included two different subsystems, one for Drivers-Adaptations and another one for Capacities (Fig. 1). In a system, elements within a cluster can interact with each other, as well as interact with elements in other clusters. The elements in a cluster are homogeneous in the sense that they share a common property. In Fig. 1, for example, cluster Climate includes the elements Temperature and Precipitation representing general characteristics of weather that are relevant to coffee in Mesoamerica. Every cluster can have an influence on itself, some, or all of the other clusters; these linkages are indicated by the arrows in Fig. 1. These connections can be within clusters, called "inner dependencies," or between clusters, called "outer dependencies." Arrows with solid points indicate that an element is decomposed in another cluster. For example, the element Climate in cluster Ecological is decomposed into elements Temperature and

Precipitation of cluster Climate. Arrows with open points indicate a linkage between elements as either inner or outer dependencies. When a system is characterized by such interdependencies and linkages between clusters, it is typically referred to as a network, regardless of the number of such interdependencies represented in the model.

In the case of the Driver-Adaptation subsystem, the clusters at the first level were organized into two hierarchies to represent Socioeconomic and Ecological drivers. Each of these was further organized into clusters containing specific elements (level 3 in the model). As characteristic of a network, the clusters exhibit interdependencies. Within the hierarchy Socioeconomic, outer dependencies connected two elements of cluster Cultural Patterns to elements of other clusters: Religious Diversity to Access to Production Processes (in cluster Social Conflict), and Participatory Governance to element New Markets (in cluster Market). These linkages reflect the recognition that increased conflict between Protestant and Catholic groups in Mesoamerica was affecting the ability of some farmers to access land for production, and that increased participation and transparency in governance was leading to new market opportunities for many farm communities. The linkage between elements Commodity Promotion (e.g., government investment in promotion of coffee markets) and New Markets (new marketing opportunities) create a feedback from cluster Agricultural Policy to the cluster Markets.

The Socioeconomic and Ecological hierarchies were further connected through the linkage between elements Labor Scarcity (in cluster Markets) and Rising Incidence of Pests/Disease and Declining Soil Fertility (the latter in cluster Biological) reflected the observation that pest problems, particularly the incidence of *Hypothenemus hampei*, the coffee berry borer, and soil erosion has increased with the labor scarcity that resulted from poor coffee prices.

The final hierarchical level in the Driver-Adaptation subsystem described the Adaptations that were expected to result from the diverse drivers that characterize the socio-ecological system of coffee farmers in Mesoamerica. Cluster Adaptations included ten elements (each representing an observed response of farmers to distinct stressors) that were evaluated in relation to specific drivers (the 32 elements) included in the clusters of hierarchies above.

The subsystem of Capacities consisted of five clusters that included the assets or capitals that were thought to be necessary for farmers to engage in specific adaptations. These were: Human (with four elements), Financial, Natural, Social (with three elements), and Physical (with two elements).

The two subsystems (Drivers-Adaptations and Capacities) were integrated into a unified structure through the linkages defined among elements in the cluster Adaptations and elements in the five clusters of capitals. For example,

Table 2 Linkages between capacities and adaptations

Capital	Element	A	B	C	D	E	F	G	H	I	J
Financial	Credit access	●	●	●	●		●	●	●	●	
	Diversified income	●	●	●		●	●	●	●	●	
	Public transfer	●	●	●	●	●	●	●		●	●
Human	Adult education	●		●	●					●	●
	Availability of household labor					●	●	●	●	●	
	Information use	●	●	●	●			●	●	●	●
	Technical assistance	●	●	●	●		●	●		●	●
Natural	Crop diversification	●		●		●					
	Irrigation availability					●	●	●			
	Landholding size						●				
Physical	Condition of rural infrastructure	●		●	●			●		●	
	Proximity to markets				●			●		●	
Social	Access to power & commercial services	●	●	●	●		●			●	
	Participation in organizations	●		●	●		●			●	●
	Social networks		●						●	●	●

A change in agricultural practices, B change in coffee variety, C change in crop, D change in marketing strategies, E decrease area in coffee, F increase area in coffee, G increase investment in time & labor, H migration, I new economic activities, J social organization

the adaptation “Change in Agricultural Practices” was linked to specific elements in each of the five capacity clusters (see Table 2). In this way, the capitals were evaluated with respect to corresponding adaptations, as shown in Table 2.

Mathematically, the set of N clusters that form an ANP network is represented as $N = \{C_a, C_b, C_c, \dots, C_n\}$, where each cluster is composed by a set of elements $C_i = \{e_{i1}, e_{i2}, \dots, e_{in_i}\}$. The set of all possible pairwise comparisons among clusters is represented as $L = \{\{C_a, C_a\}, \{C_a, C_b\}, \{C_a, C_c\}, \dots, \{C_n, C_n\}\}$, where inner dependencies are represented as $\{C_a, C_a\}, \{C_b, C_b\}$, etc., and outer dependencies as $\{C_a, C_b\}, \{C_b, C_c\}$, etc.

The pairwise comparisons in $\{C_i, C_j\}$ are arranged in a “pairwise comparison matrix,” which is solved through the eigenvector method to derive the respective “local weights.” These local weights describe each element’s relative importance in relation to the specific cluster to which it belongs. The ANP is solved through the supermatrix approach and involves arranging N as block matrices, W_{ij} , of the “unweighted supermatrix,” W , as follows:

$$W = \begin{matrix} & C_a & C_b & \dots & C_n \\ \begin{matrix} C_a \\ C_b \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} W_{aa} & W_{ab} & \dots & W_{an} \\ W_{ba} & W_{bb} & \dots & W_{bn} \\ & & \ddots & \\ W_{na} & W_{nb} & \dots & W_{nn} \end{bmatrix} \end{matrix}$$

The elements that make up the columns of W_{ij} correspond to the eigenvector solutions of the pairwise comparison

matrices within each cluster ($W_{ij} = 0$ when there are no linkages between elements of two clusters). Because some columns in W may include block matrices that link more than one cluster, some columns sums may be higher than one. In such cases, the unweighted supermatrix is normalized and synthesized to a “weighted supermatrix” that accounts for the element’s overall influence by column. The weighted supermatrix is stochastic (i.e. sum of columns equals 1), and hence the “global weights” are obtained by rising W to powers until convergence to the limit matrix is attained (i.e. columns values represent global weights for all the criteria):

$$\lim_{k \rightarrow \infty} W^k$$

In our case, the “global weights” refer to the relative importance of the drivers, adaptations and capacities with respect to the overall model goal. These global scores were normalized to “ideal weights” ($W_i = W_i/W_{max}$) and sorted out into three categories (“most important”, “important” and “less important”) that connoted their overall influence over the system (category cuts were obtained by applying the Weber-Fechner law with a progression factor of 2; see Saaty and Peniwati 2008, p 154).

Results

Drivers

The driver’s local weight (Table 3) revealed their relative importance in relation to respective block matrices, W_{ij} .

Table 3 Local importance weights of the drivers included as block matrices, W_{ij} of the unweighted supermatrix W

Hierarchy Level				Local Weight		
1st	Control Criteria	2nd Element	3rd Driver	4th & 5th		
Goal (1.00)	Socioeconomic (0.67)	Social conflict (0.06)	Access to land	0.72		
			Access to production processes	0.11		
		Market (0.42)	Cost of security	0.17		
			New markets	0.29		
			Labor scarcity	0.08		
			Prices (0.63)	Declining price ratio of organic & conventional coffee	0.21	
				Increase in input prices	0.17	
				Price ratio of alternative crops & coffee	0.08	
		Price of alternative land uses		0.04		
		Cultural patterns (0.10)	Public policy (0.42)	Increase in international coffee producer price	0.11	
				Declining international coffee producer price	0.37	
				Religious diversity	0.08	
				Participatory governance	0.20	
			(Outer dependencies)	Biological (0.33)	Global consumption	0.28
	Political pluralism				0.44	
	Climate (0.67)			Environmental policy	0.13	
				Agricultural policy (0.59)	Information	0.06
					Technical & training support	0.17
				Ecological (0.33)	Labor policy	Credit
	Commodity promotion	0.13				
	Social policy	Labor scarcity	0.09			
		Rising incidence of pest & disease	0.19			
	Temperature (0.25)	Declining soil fertility	0.25			
		Precipitation (0.75)	Torrential rainfall		0.75	
			Drought		0.67	
		Frost	Heat waves		0.33	
	Changes in mean temperature		0.31			
	Ecological (0.33)	Climate (0.67)	Heat waves	0.11		
Declining soil fertility			0.58			
Labor scarcity*		Rising incidence of pest & disease	0.67			
		Declining soil fertility	0.33			
Religious diversity*		Access to land	0.75			
		Access to production processes	0.25			
Participatory governance*	New markets	1.00				
	Agricultural policy*	New markets	1.00			
Commodity promotion*	Prices	1.00				

Drivers marked with asterisk denote outer dependencies as in Fig. 1

With respect to the goal, the socioeconomic factors were judged twice as important as the ecological ones. With respect to the socioeconomic factors, Market and Public Policy were four times more important than Cultural Patterns and eight times more important than Social Conflict.

With respect to Ecological factors, Climate was judged twice as important as Biological factors.

The outer dependency between socioeconomic and ecological drivers (through the element of Labor Scarcity; see Fig. 1) resulted in a higher local weight for Rising

Incidence of Pest & Disease than for Declining Soil Fertility, both in cluster Biological. These weights contrasted with the local weights that resulted from considering only the inner dependency of that cluster (Table 3), in which Declining Soil Fertility obtained a higher weight. With respect to the other outer dependencies in the socioeconomic network, the linkages reinforced the local weighting derived from inner dependencies (Table 3).

Influence of Specific Drivers

The ideal weights resulting from the limit supermatrix (Table 4) demonstrated the relevance of the experts' conceptualization of the coffee system as a network rather than in a more simplified hierarchal structure. If a hierarchal structure had been employed, the drivers categorized as 'most important' would have been (in rank order): Torrential rainfall, Credit, Declining Soil Fertility, New Market Opportunities, and Declining International Coffee Producer Price. However, because several outer

dependencies were incorporated into the model, the ranking of drivers reflected the transfer of weight between the socioeconomic and biological subsystems, and among clusters within the socioeconomic system resulting in the ranking described in Table 4.

As illustrated in Table 4, the experts identified not only negative "stressors" and "shocks" as drivers of change in the region, but also more gradual—and at least in part, positive—shifts in the fundamental state of the coffee sector. New Markets resulted as the most influential driver in the sector. This driver was defined as the set of institutional arrangements and benefits associated with selling coffee in niche markets (e.g., gourmet, organic, fair trade, and to a lesser extent, bird friendly) that not only has affected the structure of the sector as a whole, but also has provided new opportunities for individual farm strategies (by opening up new technological, institutional, and social-cultural relationships for farmers).

To a lesser extent, Declining International Producer Prices (particularly in relation to rising input costs) was

Table 4 Categorization of drivers with respect to the goal (global weights are normalized as ideal weights)

Category	Element	Global weight	
Most important	New markets	1.00	
	Torrential rainfall	0.63	
	Declining soil fertility	0.50	
Important	Declining international coffee producer price	0.37	
	Drought	0.31	
	Credit	0.30	
	Social policy	0.30	
	Rising incidence of pest & disease	0.25	
	Least important	Declining price ratio of organic & conventional coffee	0.21
		Environmental policy	0.20
Access to land		0.19	
Frost		0.19	
Increase in input prices		0.17	
Political pluralism		0.17	
Labor policy		0.14	
Labor scarcity		0.12	
Increase in international coffee producer price		0.11	
Global consumption		0.11	
Heat waves		0.10	
Technical & training support		0.08	
Price ratio of alternative crops & coffee		0.08	
Participatory governance		0.08	
Commodity promotion		0.06	
Price of alternative land uses		0.04	
Cost of security		0.04	
Changes in mean temperature	0.03		
Religious diversity	0.03		
Access to production processes	0.03		
Information	0.03		

considered an important driver of change in the region, despite the recent price recovery. The price shock at the end of the 1990s not only provided new incentives for farmers to seek better, alternative markets, but also altered labor availability, input use and livelihood structures throughout the region—and many of these impacts have been long-lasting. Lack of financial flexibility, represented by the contraction in farm credit, also fell into the “important” driver category, as well as the contraction in social welfare policy supports.

Among the ecological drivers, Torrential Rainfall associated with landslides and infrastructure damage, rather than more gradual climatic change, fell in the category of “most important driver.” A series of disastrous rainfall events (Hurricane Mitch; Hurricane Stan; Hurricane Wilma) had had a significant and lasting influence on the sector, both in terms of production outcomes, as well as in terms of the human welfare of the coffee producer population. A more gradual and more insidious driver of change—Declining Soil Fertility—was also identified as one of the “most important” influences on the system. Soil loss has become particularly critical in areas where torrential rainfall has also been an emergent problem for coffee producers. To a lesser extent, repeated drought, and a rising incidence of pest and disease were also important ecological drivers in the system.

Adaptations

In undertaking the pairwise comparison exercise, the experts evaluated the most important adaptations as those that (a) would be likely to be observed in the field and (b) would be preferred or desired in terms of promoting general “adaptiveness” at the farm-level (see W_{ij} in Appendix A, Table 8). On this basis, the most important adaptations included Changes in Agricultural Practices, the decision of households to organize into informal and formal social groups (Social Organization”), Reduce Area in Coffee, and Change in Crops (Table 5).

Changes in Agricultural Practices included decisions by farmers to adjust input and technology use in the coffee plantation, to invest in soil conservation or soil management, or to modify the structure of shade in coffee plantations. This category would also include other agronomic adjustments such as altering the timing or technology of particular coffee management activities (planting, weeding, pruning, harvesting) by farmers in the region. Other agronomic responses were considered separately: Change in Crops (e.g., from coffee to another crop entirely), Increase Area in Coffee and Change in Coffee Variety. These latter types of response strategies were thought by the experts to have independent impacts on the ecosystem and local

Table 5 Categorization of adaptations with respect to the goal (global weights are normalized as in Table 4)

Category	Element	Global weight
Most important	Change in agricultural practices	1.00
	Social organization	0.76
	Reduce area in coffee	0.58
	Change in crops	0.57
Important	Change in marketing strategies	0.48
	Change in coffee variety	0.45
	New economic activities	0.38
	Increase area in coffee	0.34
	Increase investment in time & labor	0.34
Least important	Migration	0.22

economies, or to be specific responses to very specific stressors, and/or to involve a different set of capacities than other types of agronomic responses described above. These responses also tend to be more permanent in terms of their impact on farm structure. Nevertheless, the pairwise comparisons weighted each of these latter responses substantially less than the broader category of “Change in Agricultural Practices.”

The second important response was that of Social Organization. This category addresses the emergence of civil society groups, cooperatives and small-business organizations as a response to the socioeconomic and environmental drivers described in the model. The decision of a farmer to participate in such an organization was thought to provide improved access to resources and knowledge, as well as to provide a social network that could potentially facilitate recovery and re-establishment of activities following severe shocks (climatic and price, for example).

Regarding Reduce Area in Coffee and Change in Crops, the experts considered that as a result of both environmental and economic stressors, farmers across the region would be increasingly exploring alternative land use strategies that did not necessarily involve coffee. As a result, the area in coffee would be observed to be declining and traditional alternatives (citrus, plantains, cocoa or pasture and livestock) or new cash crops such as flowers, exotic fruit trees (e.g., lychee, rambutan) would emerge as important alternatives.

The remaining strategies were all categorized as “important” with the exception of Migration, which was considered to be the least adaptive response in the field. Among these latter strategies, Change in Coffee Variety and Changing Marketing Strategies were thought to be particularly important as farmers sought the means to manage market volatility and environmental stressors such as drought and pests through targeting their harvests for niche markets (e.g., planting Robusta coffee for industrial use, or ‘gourmet’ high altitude coffee for higher priced markets).

Capacities

The capacity assessment resulted in the identification of three of the five clusters of capitals as most important for adaptation: Social, Human and Financial (Table 6; see W_{ij} in Appendix B, Table 9). Within these three clusters, five specific ‘capacities’ were identified as particularly influential in the ability of households to engage in the primary adaptation strategies: (1) household access to government support programs and subsidies (“public transfers” an element of the Financial Capital cluster); (2) household access to technical assistance (an element of the Human Capital cluster); (3) access to formal sources of credit (an element of the Financial Capital cluster); (4) the household having a diversified income base (and element of the Financial Capital cluster) and (5) the household’s access to and participation in farm-level organizations (an element of the Social Capital cluster).

Other important elements were: the use of information/knowledge (local, traditional or techno-scientific) in production practices, the level of education within the household and the household’s access to political power and commercial services through interpersonal connections.

Discussion

Scholars have pointed out that the scales both at which scientific or technical assessments occur are not often congruent with the scales at which biophysical and social processes occur and thus provide conflicting information for decision-making (Cash and Moser 2000). A summary of the explicit scale at which the drivers identified in this study were manifest is shown in Table 7. Several of the

specific local drivers are demonstrably linked to regional and global processes of change, identified in italics in Table 7. The ANP not only helped integrate and visualize drivers at multiple scales of analysis in a single conceptual model, but also permitted the experts to consider, to the extent information was available, feedbacks among drivers and outcomes.

Of the global drivers identified, the substantial—largely positive—impact of “new market opportunities” on households across the region is relatively well-documented in the grey literature of development agencies, as well as in sector assessments and case studies (IDB/USAID/WB 2002; Ponte 2002; Varangis and others 2003). For example, Coe (2006) finds a significant correlation between processes of market deregulation and increased participation in decision-making by farmer groups, including those in several coffee-producing nations. In his case study of a coffee producing community in Nicaragua, Bacon (2005) found that exposure to vagaries in the global market increased household vulnerabilities but that opportunities in niche markets also brought about by globalization tended to enhance livelihood security. The potential for “new market opportunities” to transform local-level outcomes is not without limits: some analysts suggest, for example, that the highly concentrated nature of the global coffee market threatens to undermine the potential for advantages in price and market share for farmers attempting to sell in organic, fair trade or other high-quality markets (Ponte 2002; Baffes and others 2005).

The discussions ensuing during the assessment process revealed that even place-specific events can have significant direct and indirect impacts that are relevant across the region, and thus can be considered “drivers of regional change.” For example, several countries in Central America were affected by severe drought conditions in 2001, 2002 and 2003 (US Agency for International

Table 6 Categorization of capacities i with respect to the goal (global weights are normalized as in Table 4)

Category	Element	Global Weight	Capital
Most important	Public transfers	1.00	Financial
	Technical assistance	0.93	Human
	Credit access	0.82	Financial
	Diversified income	0.58	Financial
	Participation in organizations	0.54	Social
Important	Information use	0.45	Human
	Adult education	0.32	Human
	Access to power & commercial services	0.22	Social
Least important	Availability of household labor	0.21	Human
	Crop diversification	0.16	Natural
	Condition of rural infrastructure	0.08	Physical
	Proximity to markets	0.05	Physical
	Social networks	0.03	Social
	Irrigation availability	0.03	Natural
	Landholding size	0.01	Natural

Table 7 Spatial and temporal scales at which the identified drivers manifest themselves

Time frame of influence	Spatial scale of manifestation		
	Local	Regional	Global
Fast (<2 years)	Torrential rainfall Pest outbreaks	Declining producer prices	
Medium (2–10 years)	Change in frequency of extreme climate events Emergence of new pests	New market opportunities Credit constraints	Change in rural policy (<i>Market liberalization</i>)
Slow (>10 years)	Loss of soil fertility	<i>(Climatic change) (Globalization)</i>	

Development (USAID) 2001) that severely affected production, rural employment and incomes. Coupled with the global phenomenon of the collapse in world coffee prices, coffee producing households and households involved in coffee labor markets across the region faced increased poverty, food insecurity and rising unemployment (IDB/USAID/WB 2002). Such climate impacts also affected the movement of labor across the region. Anecdotal information and local data indicated that migration rates increased during the coffee crisis (Emmott 2003; Hernández Navarro 2004; Eakin and others 2009; Adger and others 2009), and more recent information suggests that specific localized events, such as the impact of Hurricane Stan in Guatemala and Mexico, disrupts the movement of labor and harvests both within and between countries.

As noted in the Millennium Ecosystem Assessment, assessing responses to broader-scale drivers is a difficult but necessary task (Hassan and others 2005). The experts participating in this assessment recognized the potential of farmers' responses to feedback and affect system drivers, although the lack of empirical evidence prevented the inclusion of cross-scale feedbacks between adaptations and drivers in the assessment model. Ideally responses of households, governments and other organizations would result in both improvements in ecosystem functions and the provision of ecosystem services, while enhancing human well-being. For example, in order to sell coffee in an organic or gourmet commodity market, farmers will likely have to change their mode of production, including making agronomic adjustments in input use, soil and shade management and harvesting techniques. These agronomic adjustments will in turn likely affect the incidence of pests and microclimatic conditions in coffee plantations, mediating the impact of such drivers as "climate" and "pests" on farm-level outcomes. Recently, for example, Lin (2007) found evidence that effective management of shade in coffee production can help mitigate variations in soil moisture and microclimatic parameters, a common practice among coffee growers in response to varying levels of rainfall availability. Additional empirical evidence of these

linkages, however, is only beginning to be known. A separate model outlining these potential cross-scale interactions would be a next step in the modeling effort and might assist policy-makers in responding to farm-level change.

The experts in our assessment also emphasized the role of knowledge—local knowledge as well as technical knowledge—and information in responding to the global environmental and market challenges facing the coffee sector, as well as the critical role that social organization plays not only as a *response* to stress but also in its own right as a capacity to facilitate other forms of adaptations, such as access to markets, technology, information, and other resources. There has been a wealth of scientific and advocacy literature extolling the benefits of farm-level organization as a response strategy to the restructuring and liberalization of the global coffee market in the 1990s (see, for example, (Hernández Navarro and Célis Callejas 1994; Nigh 1997; Bray and others 2002; IDB/USAID/WB 2002; Morrison 2003; Bezaury 2007). Nevertheless, other research has identified significant obstacles and capacity constraints that may diminish the benefits of farmers' participation in cooperatives and social networks to sell coffee in new markets (Bray and others 2002; Mutersbaugh 2002). For example, economic stress at the household level often undermines a farmers' commitment to the activities of farm-level organizations, and in some areas farmers are simply unaware of the existence of farm cooperatives and are generally distrustful of their operations (Eakin and others 2006).

Similarly, the importance in the assessment given to technical and financial capacity in enabling adaptation is logical, and indicates that in order for agronomic adjustments to occur, some level of public sector and civil-society involvement will be necessary. Supporting adaptive innovations in farm practices is not trivial: funding for agricultural research and extension has generally declined across the Mesoamerican region over the last 15 years, and many farmers lack financial support that would allow them to take risks in adopting new, alternative technologies and production practices (see discussion in Eakin and Lemos

2006). Labor scarcity resulting from increasing rates of emigration is also a limiting factor in adopting some new practices.

Economic and cash-crop diversification are well-recognized generic strategies for farm households to manage risk and adapt to change (Agrawal and Perrin 2008), although in this assessment these strategies were considered of lesser relative importance. This can be interpreted in the light of significant limitations associated with such strategies in the Mesoamerican coffee sector. The vast majority of coffee farmers in the region survive in both economic and geographic margins, in which alternative employment, educational opportunities and market access is limited. Without access to finance, some strategic choices are also simply out of reach, particularly when they involve some degree of risk such as the adoption of new crops, or engagement in new economic strategies. Vegetable and fruit production, for example, may be perceived by farmers as far more risky than coffee. Farmers are familiar with the coffee market and its volatility. While they may face low prices, there have been only a few circumstances (the recent coffee crisis being one example) in which they have simply not been able to commercialize their crop. Vegetables, on the other hand, are highly perishable and market failures can mean significant economic risk and loss for producers (Eakin 2003). Natural capital constraints—such as the ecological and topographic conditions in which coffee grows—also limits alternative land use and crop options.

The remaining response strategies discussed and weighed by the experts were revealed to be relatively less influential in the process of adaptation, or, in some cases, of ambiguous adaptive importance. For example, while farmers can be expected to reduce or expand planted area in response to some market and climate signals, coffee is a tree-crop associated with high investment costs. For this reason households are often reluctant to voluntarily reduce their area planted, and while expansion of production is possible in some areas, access to land is already scarce or constrained across most of the region (Tucker and others 2010). Similarly, while migration is definitely on the rise in many parts of Mesoamerica, it appeared that migration in coffee households was difficult to link specifically to the identified drivers. This reflected the fact that it was not obvious to the experts whether migration was ultimately an adaptive strategy or not.

Conclusions

The assessment of the Mesoamerican coffee sector illustrates that there are indeed similar processes at work across

the Mesoamerican region, despite very significant differences in local ecology, culture, and political-economy. While it would be unreasonable to expect that the identified drivers and responses would manifest in all places across the region, the experts concurred that there were some broad-brush similarities that could inform policy and hence inform the structure and function of a regional social-ecological system.

While many of the drivers identified in the assessment must be considered essentially exogenous stressors in relation to any policy domain at the national level (e.g., climate change or global price fluctuations), the assessment did provide insights into where policy intervention might be most appropriate. By identifying local-level capacities considered to be most important for achieving desirable farm level responses, the experts highlighted areas in which policy might have the greatest influence on adaptation. In particular, the assessment emphasizes that there is a need for interventions to support the autonomous agronomic adjustments (and the local knowledge employed in such actions) that appear to be giving farmers advantages in face of new markets and environmental change. Facilitating adaptation will involve renewed attention to helping households acquire information about markets and new technology. In face of declining public investment in agriculture, it is clear that public support for research on low-cost, low-input strategies to manage climatic extremes and to improve the quality of coffee in global markets is also necessary. Finance is critical: access to microloans and formal credit for farm-level investments will help households strategically invest in coffee varieties, complementary crops and livelihood enhancements that effectively reduce risk and improve social welfare.

The assessment revealed the important role of social organization and social capital in the adaptation process. The crucial role of civil society in rural development is already recognized, and its function in the coffee sector is well-known. Further support for social organization will likely enable rural households to access the resources and knowledge necessary for adaptation, while empowering communities to shape the direction of the coffee sector to meet their diverse development needs.

Acknowledgments The activities reported in this paper were financed by the University of California Pacific Rim Research Program. Any opinions, findings, conclusions and recommendations are those of the authors and do not necessarily reflect the views of Pacific Rim Research Program. The authors are grateful for the contributions and active participation of S Hernández, MV Gottret, H Morales, S Urioste, G Jiménez, W McLaughlin, JF Barrera, R Díaz, C Tucker, D Morales-Hidalgo in the construction of the AHP model. We appreciate the helpful suggestions of three anonymous reviewers in improving this manuscript.

Appendix A

See Table 8

Table 8 Block matrices, W_{ij} , relating drivers and adaptation for the unweighted supermatrix of the coffee sector ANP model in Mesoamerica

Adaptation	Driver								
	CPt		PuP			Mrk	SoC		
	GIC	PPI	EnP	LaP	SoP	NMk	AcL	APP	CSe
Change in agricultural Practices	0.00	0.00	0.80	0.60	0.00	0.16	0.00	0.16	0.00
Change in crop	0.00	0.00	0.00	0.00	0.09	0.04	0.00	0.00	0.00
Change in coffee variety	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Change in marketing Strategies	0.14	0.00	0.20	0.00	0.00	0.34	0.00	0.25	0.00
Increase area in coffee	0.00	0.00	0.00	0.00	0.07	0.14	0.07	0.00	0.00
Increase in time & labor	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
Migration	0.57	0.00	0.00	0.00	0.12	0.00	0.23	0.00	0.40
New economic activities	0.29	0.17	0.00	0.00	0.26	0.00	0.27	0.00	0.00
Reduce area in coffee	0.00	0.00	0.00	0.20	0.00	0.00	0.13	0.00	0.20
Social organization	0.00	0.83	0.00	0.00	0.45	0.25	0.31	0.59	0.40

Adaptation	Driver									
	AgP				Prc					
	CoP	Cre	Inf	TTS	DCP	ICP	IIP	PLU	RAC	ROC
Change in agricultural Practices	0.00	0.13	0.17	0.30	0.13	0.00	0.25	0.00	0.00	0.16
Change in crop	0.00	0.19	0.16	0.19	0.12	0.00	0.07	0.00	0.53	0.00
Change in coffee variety	0.00	0.00	0.07	0.06	0.00	0.00	0.06	0.00	0.00	0.00
Change in marketing Strategies	0.50	0.10	0.31	0.17	0.07	0.00	0.00	0.00	0.00	0.30
Increase area in coffee	0.00	0.16	0.00	0.00	0.00	0.75	0.00	0.00	0.09	0.00
Increase in time & labor	0.00	0.07	0.00	0.00	0.00	0.25	0.16	0.00	0.00	0.00
Migration	0.00	0.05	0.07	0.00	0.17	0.00	0.00	0.00	0.00	0.00
New economic activities	0.00	0.13	0.00	0.00	0.27	0.00	0.12	0.50	0.00	0.00
Reduce area in coffee	0.00	0.00	0.00	0.00	0.06	0.00	0.13	0.50	0.22	0.00
Social organization	0.50	0.16	0.21	0.28	0.18	0.00	0.21	0.00	0.16	0.54

Adaptation	Driver							
	Bio		Tem			Pre		
	DSF	RDP	CMT	Fro	HeW	Dro	ToR	
Change in agricultural practices	0.55	0.52	0.67	0.80	0.80	0.34	0.61	
Change in crop	0.12	0.14	0.00	0.00	0.00	0.19	0.00	
Change in coffee variety	0.00	0.15	0.33	0.20	0.20	0.14	0.00	
Change in marketing strategies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Increase area in coffee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Increase in time & labor	0.24	0.19	0.00	0.00	0.00	0.00	0.00	
Migration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
New economic activities	0.00	0.00	0.00	0.00	0.00	0.19	0.00	
Reduce area in coffee	0.09	0.00	0.00	0.00	0.00	0.14	0.17	
Social organization	0.00	0.00	0.00	0.00	0.00	0.00	0.22	

CPt cultural patterns, GIC global consumption, PPI political pluralism, PuP public policy, EnP environmental policy, AgP agricultural policy, LaP labor policy, SoP social policy, Mrk market, NMk new markets, SoC social conflict, AcL access to land, APP access to production processes, CSe cost of security, CoP commodity promotion, Cre credit, Inf information, TTS technical & training support; Prc prices, DCP decrease in international coffee producer price, ICP increase in international coffee producer price; IIP increase in input prices, PLU price of alternative land uses, RAC price ratio of alternative crops & coffee, ROC decrease in price ratio of organic & conventional coffee, Bio biological, DSF declining soil fertility, RPD rising incidence of pest & disease, Pre precipitation, ToR torrential rainfall, Dro drought, Tem temperature, CMT changes in mean temperature, Fro frost, HeW heat waves

Appendix B

See Table 9

Table 9 Block matrix, W_{ij} , relating adaptation and capacities for the unweighted supermatrix of the coffee sector ANP model in Mesoamerica

Capacity	Adaptation									
	A	B	C	D	E	F	G	H	I	J
Financial capitals										
Credit access	0.16	0.30	0.31	0.33	0.00	0.53	0.54	0.33	0.16	0.00
Diversified income	0.54	0.54	0.49	0.00	0.75	0.33	0.30	0.67	0.30	0.00
Public transfers	0.30	0.16	0.20	0.67	0.25	0.14	0.16	0.00	0.54	1.00
Human capitals										
Adult education	0.11	0.00	0.16	0.16	0.00	0.00	0.00	0.33	0.16	0.11
Availability of household labor	0.00	0.00	0.09	0.00	1.00	0.50	0.63	0.67	0.32	0.00
Information use	0.55	0.67	0.31	0.30	0.00	0.00	0.14	0.00	0.12	0.55
Technical assistance	0.34	0.33	0.43	0.54	0.00	0.50	0.24	0.00	0.40	0.34
Natural capitals										
Crop diversification	1.00	0.00	0.16	0.00	0.33	0.00	0.00	0.00	0.00	0.00
Irrigation availability	0.00	0.00	0.30	0.00	0.67	0.25	1.00	0.00	0.00	0.00
Landholding size	0.00	0.00	0.54	0.00	0.00	0.75	0.00	0.00	0.00	0.00
Physical capitals										
Condition of rural infrastructure	1.00	0.00	0.25	0.25	0.00	0.00	0.67	0.00	0.25	0.00
Proximity to markets	0.00	0.00	0.75	0.75	0.00	0.00	0.33	0.00	0.75	0.00
Social capitals										
Access to power & commercial services	0.25	0.20	0.25	0.20	0.00	0.25	0.00	0.00	0.25	0.00
Participation in organizations	0.75	0.80	0.75	0.80	0.00	0.75	0.00	0.00	0.16	0.25
Social networks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.59	0.75

A change in agricultural practices, *B* change in coffee variety, *C* change in crop, *D* change in marketing strategies, *E* decrease area in coffee, *F* increase area in coffee, *G* increase investment in time & labor, *H* migration, *I* new economic activities, *J* social organization

References

- Adger WN, Eakin H, Winkels A (2009) Nested and networked vulnerabilities to global environmental change. *Frontiers in Ecology and the Environment* 7(3):150–157. doi:10.1890/070148
- Agrawal A, Perrin N (2008) Climate adaptation, local institutions, and rural livelihoods. IFRI Working Paper #W08I-6. School of Natural Resources and Environment, University of Michigan, Ann Arbor
- Bacon C (2005) Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua? *World Development* 33(3):497–511
- Baffes J, Lewin B, Varangis P (2005) Coffee: market setting and policies. In: Aksoy MA, Beghin JC (eds) *Global agricultural trade and developing countries*. The World Bank, Washington, pp 297–309
- Baker P, Haggard J (2007) Global warming: the impact on global coffee. SCAA Conference Handout, Long Beach, p 14
- Bebbington A (1999) Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. *World Development* 27(12):2021–2044
- Bezaury JA (2007) Organized coffee producers: mitigating negative impacts of outmigration in Oaxaca, Mexico. *Mountain Research and Development* 27(2):109–113
- Bray DB, Sanchez JLP, Murphy EC (2002) Social dimensions of organic coffee production in Mexico: lessons for eco-labeling initiatives. *Society & Natural Resources* 15(5):429–446
- Cash D, Moser SC (2000) Linking global and local scales: designing dynamic assessment and management processes. *Global Environmental Change* 10:109–120
- Castellanos EPI (2006) Effective adaptation strategies and risk reduction towards economic and climatic shocks: lessons from the coffee crisis in Mesoamerica. Inter American Institute for Global Change Research, CRN Grant #2-060. Universidad de Valle de Guatemala, Guatemala City
- Coe CA (2006) Farmer participation in market authorities of coffee exporting countries. *World Development* 34(12):2089–2115
- Eakin H (2003) The social vulnerability of irrigated vegetable farming households in central Puebla. *Journal of Environment and Development* 12:414–429
- Eakin H, Bojórquez-Tapia LA (2008) Insights into the composition of household vulnerability from multicriteria decision analysis. *Global Environmental Change-Human and Policy Dimensions* 18:112–127
- Eakin H, Lemos MC (2006) Adaptation and the state: Latin America and the challenge of capacity-building under globalization. *Global Environmental Change* 16:7–18
- Eakin H, Tucker C, Castellanos E (2006) Responding to the coffee crisis: a pilot study of farmers' adaptations in Mexico,

- Guatemala and Honduras. *The Geographical Journal* 172(2): 156–171
- Eakin H, Winkels A, Sendzimir J (2009) Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. *Environmental Science and Policy* 12(4):398–412
- Ellis F (2000) *Rural livelihoods and diversity in developing countries*. Oxford University Press, Oxford, p 300
- Emmott R (2003) Coffee crisis creates a panama ghost town. *The Toronto Star*, Toronto, C11
- Gay Garcia C, Estrada F, Conde C, Eakin H, Villers L (2006) Potential impacts of climate change on agriculture: a case of study on coffee production in Veracruz, Mexico. *Climatic Change* 79:259–288
- Hassan R, Scholes R, Ash N (eds) (2005) *Ecosystems and human well-being: current state and trends assessment*. Millennium Ecosystem Assessment. Island Press, Washington, p 917
- Hernández Navarro L (2004) To die a little: migration and coffee in Mexico and Central America. Interhemispheric Resource Center, Silver City, NM
- Hernández Navarro L, Célis Callejas F (1994) Solidarity and the new campesino movements: the case of coffee production. In: Cornelius WA, Craig AL, Fox J (eds) *Transforming state-society relations in Mexico*. Center for US-Mexican Studies, University of California San Diego, La Jolla, pp 217–231
- Hulme M, Sheard N (1999) *Climate change scenarios for Mesoamerica*. Climate Research Unit, UEA, Norwich
- IDB/USAID/WB (2002) *Transición competitiva del sector cafetalero en Centroamérica*. Antigua, Banco Interamericano de Desarrollo/Agencia de los Estados Unidos para el Desarrollo Internacional/Banco Mundial
- International Coffee Council (2003) *Impact of the coffee crisis on poverty in producing countries*. International Coffee Organization, Eighty-ninth Session
- International Coffee Council (2009) *Climate change and coffee*. International Coffee Organization, 103rd Session, 23–25 Sep 2009, London, England
- International Coffee Organization (2001) *The first ICO world coffee conference: Report of the proceedings*. First World Coffee Conference, London, UK
- IPCC (ed) (2007) *Climate change 2007: the physical science basis*. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, p 976
- Kessler JJ, Rood T, Tekelenburg T, Bakkenes M (2007) Biodiversity and socioeconomic impacts of selected agro-commodity production systems. *The Journal of Environment and Development* 16:131–160
- Lewin B, Giovannucci D, Varangis P (2004) *Coffee markets: new paradigms in global supply and demand*. World Bank Agriculture and Rural Development Discussion Paper 3. Washington, pp 149
- Lin BB (2007) Agroforestry management as an adaptive strategy against potential microclimatic extremes in coffee agriculture. *Agriculture and Forest Meteorology* 144:84–94
- Manson R (2004) Los servicios hidrológicos y la conservación de los bosques de México. *Madera y Bosques* 10(1):3–20
- Morrison K (2003) “Co-operation” needed to stop coffee crisis. *The Financial Times*, London, p 9
- Mutersbaugh T (2002) The number is the beast: a political economy of organic-coffee certification and producer unionism. *Environment and Planning A* 34(7):1165–1184
- Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: contributions of a resilience framework. *Annual Review of Environment and Resources* 32:395–419
- Nigh R (1997) Organic agriculture and globalization: a Maya associative corporation in Chiapas, Mexico. *Human Organization* 56(4):427–436
- Pérez-Nieto J, Valdés-Velarde E, Hernández-San Román M, Ordaz-Chaparro V (2005) Lluvia, escurrimiento superficial y erosión del suelo en sistemas agroforestales de café bajo sombra. *Agrociencia* 39:409–418
- Petschel-Held G, Lasco R (2005) Drivers of ecosystem change. In: Capistrano D, Samper CK, Lee MJ, Raudsepp-Hearne C (eds) *Ecosystems and human well-being: multiscale assessments: findings of the sub-global assessments working group of the millennium ecosystem assessment*. Island Press, Washington, DC, pp 141–169
- Philpott SM, Lin BB, Jha S, Brines SJ (2008) A multi-scale assessment of hurricane impacts on agricultural landscapes based on land use and topographic features. *Agriculture, Ecosystems and Environment* 128:12–20
- Pineda E, Halffter G (2004) Species diversity and habitat fragmentation: frogs in a tropical montane landscape in Mexico. *Biological Conservation* 117:499–508
- Ponte S (2002) *The coffee crisis. Aid policy and practice*. Centre for Development Research, Copenhagen, pp 1–4
- Richter M (2000) The ecological crisis in Chiapas: a case study from Central America. *Mountain Research and Development* 20(4): 332–339
- Saaty TL (2001) *The analytic network process: decision making with dependence and feedback*. RWS Publications, Pittsburgh, p 386
- Saaty TL, Peniwati K (2008) *Group decision making: drawing out and reconciling differences*. RWS Publications, Pittsburgh, p 385
- Scoones I (1998) *Sustainable rural livelihoods: a framework for analysis*. IDS Working Paper #72, Institute for Development Studies, Sussex
- Siegel P, Alwang J (1999) *An asset-based approach to social risk management: a conceptual framework*. Social protection discussion paper series. Social Protection Unit, The World Bank, Washington
- Tucker C, Eakin H, Castellanos E (2010) Perceptions of risk and adaptation: coffee producers, market shocks and extreme weather in Central America and Mexico. *Global Environmental Change* 20:23–32
- US Agency for International Development (USAID) (2001) *USAID fact sheet: Central American drought, update #5*. USAID, Washington
- Varangis P, Siegel P, Giovannucci D, Lewin B (2003) *Dealing with the coffee crisis in Central America: impacts and strategies*. World Bank, Washington