Hum Nat (2007) 18:162–180
DOI 10.1007/s12110-007-9007-z

Perception of Interannual Covariation and Strategies for Risk Reduction among Mikea of Madagascar

Individual and Social Learning

Bram Tucker

Published online: 26 June 2007

Abstract This paper begins with the hypothesis that Mikea, participants in a mixed foraging–fishing–farming–herding economy of southwestern Madagascar, may attempt to reduce interannual variance in food supply caused by unpredictable rainfall by following a simple rule-of-thumb: Practice an even mix of activities that covary positively with rainfall and activities that covary negatively with rainfall. Results from a historical matrix participatory exercise confirm that Mikea perceive that foraging and farming outcomes covary positively or negatively with rainfall. This paper further considers whether Mikea learn about covariation through personal observation and memory recall (individual learning) or through socially transmitted ethnotheory (social learning). Dual inheritance theory models by Boyd and Richerson (1988) predict that individual learning is more effective in spatially and temporally variable environments such as the Mikea Forest. In contrast, the psychological literature suggests that individuals judge covariation poorly when memory of past events is required, unless they share a socially learned theory that a covariation should exist (Nisbett and Ross 1980). Results suggest that Mikea rely heavily on shared ethnotheory when judging covariation, but individuals continually strive to improve their judgment through individual observation.

Keywords Covariation perception · Diversification · Madagascar · Risk · Social learning

Covariation, Diversification, and Risk

In unpredictable environments, the subsistence forager, farmer, or herder may seek to understand natural covariant relationships so as to predict future climatic conditions and gain better control over economic outcomes. For example, Andean

B. Tucker (✉)
Department of Anthropology, University of Georgia, 250A Baldwin Hall, Jackson St., Athens, GA 30602, USA
e-mail: bramtuck@uga.edu

farmers gather on mountain summits near the winter solstice to observe the Pleiades star cluster, with the belief that the number and brilliance of visible stars predicts how much rain will fall in the subsequent year (Orlove et al. 2002). North Americans are familiar with folksy covariation hypotheses such as the color of woolly-bear caterpillars (*Pyrrharctia isabella*) in autumn predicting the severity of the upcoming winter, or a particular groundhog in Pennsylvania predicting the onset of warmer weather by the presence or absence of its shadow on February 2. Some perceived covariations are consistent with scientifically verifiable causal relationships. The visibility of the Pleiades in the southern hemisphere is determined by the presence of cirrus clouds in the upper atmosphere, which are common during El Niño years and otherwise absent. Andean farmers successfully predict annual rainfall 65% of the time, which is slightly *better* than scientific meteorological predictions (Orlove et al. 2002:433). Other perceived covariations, such as Punxsutawney Phil's shadow and the onset of vernal weather, are most likely spurious.

Covariation is a significant statistical, psychological, and economic concept because this is how humans and other animals learn about causal relationships and seek to control them. The statistician uses formal models of contingency, correlation, and regression to demonstrate predictive relationships between, for example, public hygiene factors and disease prevalence, or social factors and crime rates. Policy-makers then use these statements of causality in their attempts to control public health and safety. Psychologists are interested in covariation perception because, to some extent, humans and other animals are naive statisticians who seek to understand and control their environments (Inhelder and Piaget 1958; Kelley 1973). Operant conditioning, one of the simplest forms of individual learning, is simply the recognition of a co-occurrence of behavior X and reward Y.

In economics, covariation is related to control over risk, where risk is defined as unpredictable variation. For the capitalist investor, covariation in the value of investments determines the riskiness of a portfolio. Markowitz (1952) argues that diversification alone will fail to reduce risk if the value of individual stocks fluctuate synchronously over time, regardless of how many stocks are included (Fig. 1a). A portfolio consisting of shares in three coalmines is much riskier than a similarly sized portfolio consisting of one share in coal, one in manufacturing, and one in real estate. Markowitz advises investors to choose portfolios that maximize mean returns while minimizing correlation coefficients (Fig. 1b).

Anthropologists have recognized the significance of covariation for controlling risk in non-capitalist economies as well. Among foragers, food sharing diversifies the pool of individuals supplying food; food storage diversifies time units over which the food may be consumed; and mobility diversifies terrain over which food is harvested. Analogous to Markowitz's rule, Winterhalder (1986, 1990) argues that food sharing can only reduce risk if there is low covariance in the success rate of multiple foragers: if, on a given day, some foragers are likely to succeed and others are likely to fail independently of one another. As inter-forager covariance increases, more independent foragers are required to successfully reduce risk. Likewise, storage reduces risk only if temporal covariation is low. Harpending and Davis (1977) assert that spatial covariation (they use the word "coherence") determines the efficacy of mobility and territoriality to reduce risk (see also Cashdan 1992).

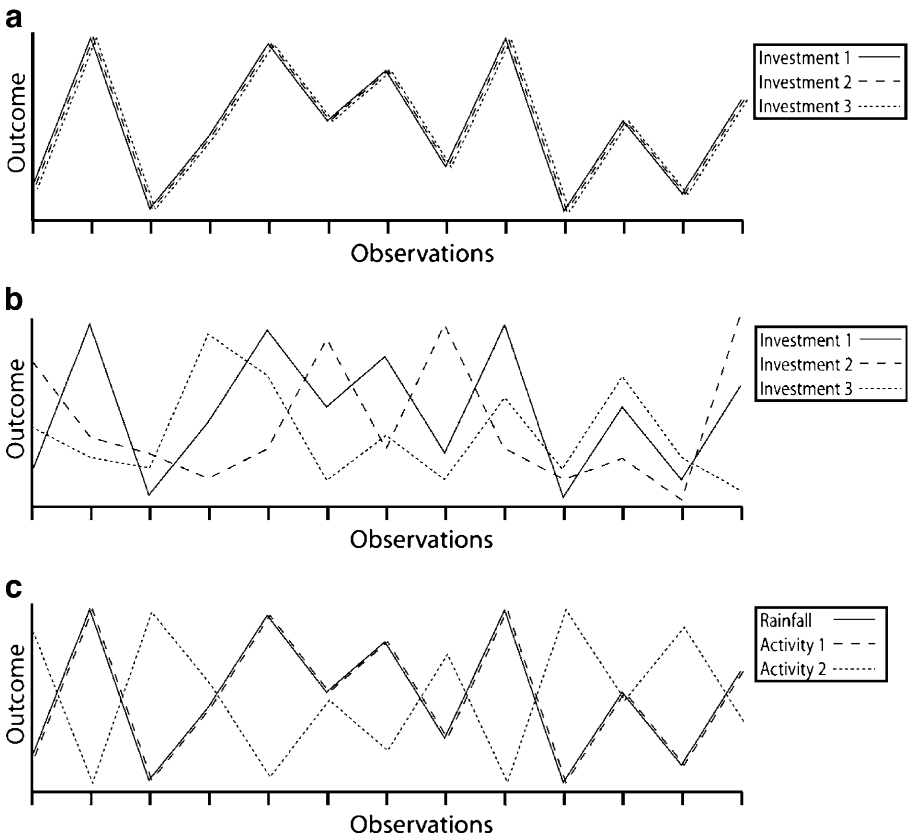

Fig. 1 Whether diversification reduces risk depends on covariance among investments. **a** Financial economist Markowitz (1952) warns that if investments have high positive covariance, the portfolio does not reduce risk. **b** He recommends that investors maximize mean return while also minimizing covariance. **c** For Mikea "investors," a simpler and potentially more effective rule-of-thumb would be to combine activities with high positive covariance with rainfall and activities with high negative covariance with rainfall. Whereas **b** still results in the occasional shortfall, **c** eliminates risk entirely

This paper explores whether Mikea and their neighbors in southwestern Madagascar perceive covariation between annual precipitation and the outcomes of food production activities, and whether they use this information to reduce the risk of food shortage. Although Mikea self-identify as hunter-gatherers, in practice all households maintain diversified portfolios of foraging, fishing, farming, herding, and marketing activities (Tucker 2001). The success of many activities in this dry environment is contingent on rainfall.

Mikea are to some degree analogous to other investors in that the household has a limited budget (of labor) to allocate to a spectrum of investments (food production activities). This paper explores the hypothesis that Mikea follow a simplier, and potentially more effective, version of Markowitz's rule when choosing which activities to include in their portfolios. Figure 1b demonstrates that multiple uncorrelated investments may still, by chance, fail simultaneously. A simple rule-of-thumb is sufficient to prevent this: practice an even mix of activities that covary positively with rainfall along with activities that covary negatively with rainfall (Fig. 1c). To the extent that covariation is predictable, a combination of positive and negative covariations cancels out variation and eliminates risk.

Covariation Perception, Evolution, and Learning

If Mikea follow simple rules to balance positive and negative covariation in their portfolios, how do they come to know causal relationships between rainfall and foraging and farming outcomes? One possibility is that individuals independently perceive rainfall and the outcomes of food production activities on an annual basis, and then judge covariation based on longitudinal memory from past years. Human behavioral ecology justifies individual learning with evolutionary theory. Because natural selection acts primarily at the level of individual fitness (Williams 1966), the ability of the individual to perceive and evaluate has been honed over evolutionary time (Winterhalder and Smith 1992).

The alternative explanation is that Mikea learn about covariation through "social learning." Dual inheritance theory argues that because individual perception is imperfect and costly, individuals may gain greater benefits by selectively copying the behavior of others (Boyd and Richerson 1985, 1988, 2001; Henrich and McElreath 2003). Mikea may judge covariation using theories that conform to majority opinion or to the opinions of prestigious or successful individuals.

Boyd and Richerson (1988, 2001) have modeled the conditions under which individual versus social learning strategies are more effective. Their model imagines a scenario in which the climate fluctuates randomly between two states. Individuals may choose between two strategies, each adapted to one of the two climatic states. Individuals may either trust their observations of the climate (individual learning), with the hazard of misperception and misjudgment, or they may imitate the strategy of a random individual in a previous cohort (social learning), with the hazard that the copied individual may be practicing the maladaptive strategy. Because perception is imperfect, observations of the environment may be abstracted as a frequency distribution. A decision-maker will doubt her own judgment and choose to imitate unless the majority of this distribution exceeds a "distinctiveness threshold."

The model predicts that social learning will produce the greatest fitness payoffs under a wide variety of conditions. However, individual learning may work better when perception is accurate, or when the climatic states are sufficiently extreme that even poor perception is adequate to discern differences. Individual learning is also preferred when there is an elevated chance that the previous cohort practiced the maladaptive strategy. This may be the case when the environment is spatially variable and there is substantial migration, and when the environment is temporally variable.

Most of these conditions apply to the Mikea scenario. Climatic states (dry and rainy years) and economic outcomes (food surplus or scarcity) are quite distinct. Rainfall is spatially variable, and people are mobile. There is high interannual variability in rainfall. Mikea should find individual learning beneficial.

However, the experimental psychology literature casts doubt on individuals' abilities to perceive covariation at interannual and other large time scales for which accurate longitudinal memory is required. Ward and Jenkins (1965) demonstrate that while subjects may accurately perceive covariation among data summarized in a table, we find it difficult to see relationships when data are experienced as a series of observations. Decision-makers overconfidently judge trends from an insufficient sample of observations (Tversky and Kahneman 1974). Memory also has what Tversky and Kahneman (1973, 1974) call a "retrievability bias"; we overemphasize the frequency of extreme, rare, and emotionally significant events, for they are easier to recall.

In judging contingency (does rain make flowers bloom?), we often use simple heuristics that pay attention to some information—usually, how frequently two phenomena co-occur (rain and flowers)—while ignoring equally relevant information—how frequently one phenomenon occurs in the absence of the other (no rain with flowers; rain with no flowers), and how frequently neither phenomenon occurs (no rain, no flowers) (Inhelder and Piaget 1958; Shaklee and Mims 1981; Shaklee and Tucker 1980). Decision-makers who use complex heuristics when judging covariation in ideal circumstances switch to simpler heuristics for memory-intensive tasks (Shaklee and Mims 1982).

Based on this evidence, Nisbett and Ross (1980) conclude that the basic capacity of the individual to perceive covariation is quite poor, unless there is prior expectation that a correlation *ought* to exist. Prior expectation is significant enough to cause people to perceive covariations that do not exist, a phenomenon known as "illusory correlation" (Chapman 1967). Nisbett and Ross (1980) further speculate that humans inherit many covariation theories through social learning. "Each culture has experts, people of unusual acumen or specialized knowledge, who detect covariations and report them to the culture at large" (Nisbett and Ross 1980: 111).

For Mikea, rainfall and economic outcomes constitute a series of events with an annual delay between observations, so that judgment must be based on memory of a small sample of observations. Extreme events such as droughts and cyclones would bias memory by being differentially retrievable. In contrast to the predictions of Boyd and Richerson's model, the psychological literature predicts that Mikea judge covariation using social learning, in the form of culturally inherited ethnotheories—what has been termed *traditional environmental knowledge* (Hunn et al. 2003; Johannes 1989).

Predictions

This investigation of perception of covariation between rainfall and economic outcomes involves a "historical matrix" participatory exercise (Freudenberger 1994, 1996) conducted in 14 sites within and around the Mikea Forest (Fig. 2). In the historical matrix, a group of local informants completes a tabular grid in which rows represent units of time (in this case the years 1999–1995); columns are variable phenomena (rainfall, economic outcomes); and each cell is filled with counters to represent abundance of the phenomenon in that time unit. These data are applied to the following predictions:

1. If Mikea perceive covariation between rainfall and the outcomes of food production activities, the historical matrix exercise should reveal positive and negative covariations consistently at all sites.

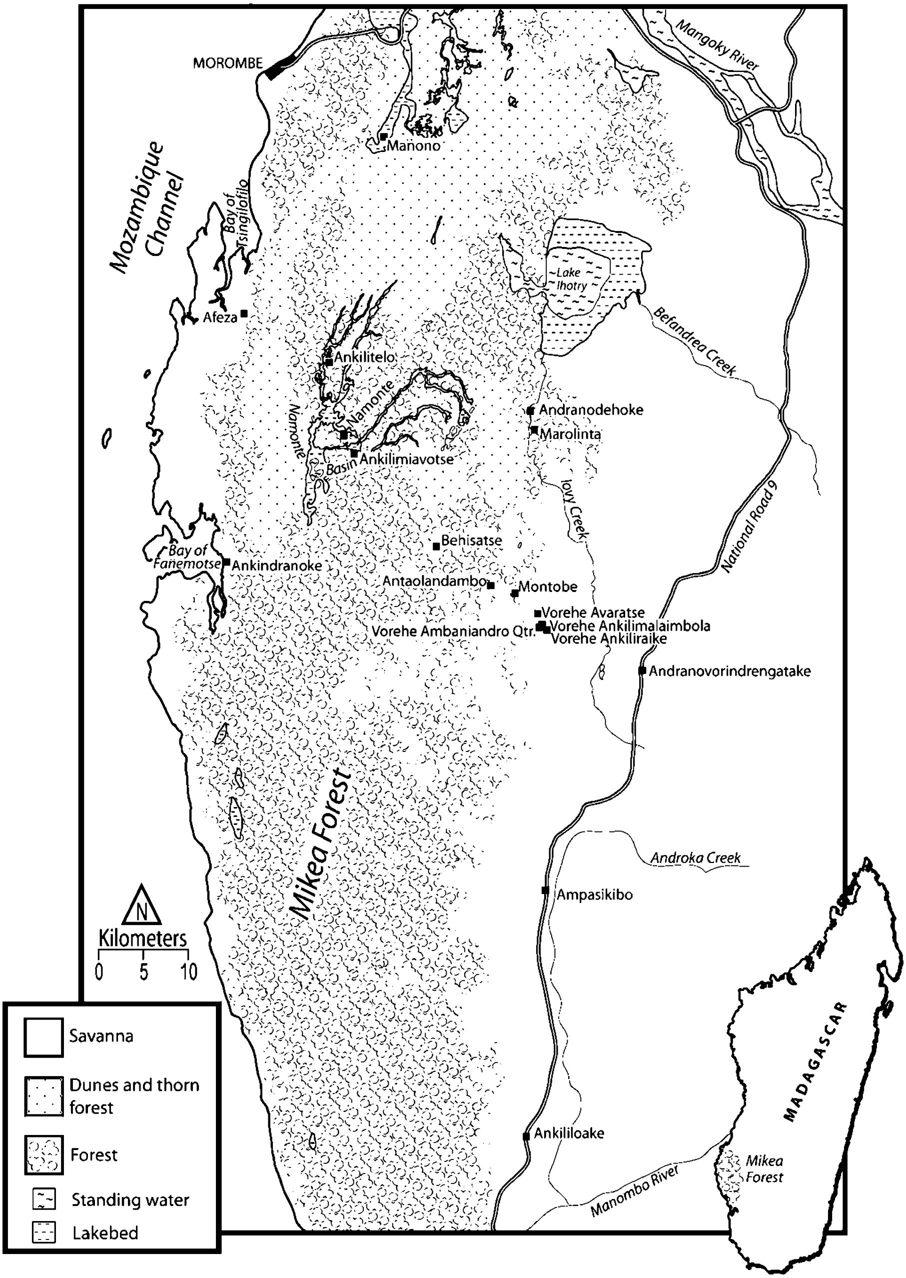

Fig. 2 Map of the Mikea Forest region, showing the 14 field sites and the three HASYMA weather stations, and other placenames mentioned in text

2. If the identified covariations are accurate (due to either accurate individual perception or accurate ethnotheory), they should be consistent with available production and market data.

3. If covariation perception is based on individual learning, participants should discuss mnemonic events while completing the matrix. If based on social learning, discussion of cause-and-effect rules should drive completion of the exercise.
4. If perceived covariation is based on accurate memory of past events, then rainfall amounts expressed quantitatively in the historical matrix exercise should be concordant with actual rainfall data from local weather stations.
5. If perceived covariation is based on accurate memory of past events, participants at sites in close proximity to one another should remember events with greater agreement than participants at distant sites.

Ethnographic Background

People and Field Sites

Mikea idealize themselves and are considered by other Malagasy to be forest-dwelling hunter-gatherers. Yet in practice, all Mikea households combine foraging and fishing with agriculture, herding, and market-oriented activities (Tucker 2001). Mikea are closely related to neighboring Masikoro agropastoralists and Vezo fishers through common history and genealogy. Oral histories indicate that Mikea are descended from Masikoro and Vezo who sought refuge in the dry Mikea Forest (Alamikea) during the past four or more centuries. The original Mikea may have been cattle pastoralists who fled the livestock and slave raids of the Andrevola kings, as well as warfare-related food scarcity and interpersonal conflicts. Others became Mikea during the twentieth century to escape the forced relocation schemes, mandatory labor, and taxes of the French colonial authority. The Mikea reputation for forest residence and foraging does not connote economic specialization; rather, it symbolizes political autonomy from royal, colonial, and postcolonial control (Tucker 2003; Yount et al. 2001).

Table 1 summarizes the 14 field sites, and Fig. 2 locates them geographically. The savanna villages of Vorehe, Marolinta, Andranodehoke, Mañono, and the coastal villages of Afeza and Ankindranoke are permanent settlements (population 300 to 1,400) founded in the early twentieth century as the result of French colonial policies to forcibly resettle nomadic foragers and herders. Vorehe is the largest village (1,400 people) and home to a Lutheran mission, church, and medical dispensary, as well as a market held each Wednesday. The matrix was conducted in four historically distinct neighborhoods of Vorehe, with a new set of participants at each. The small villages of the Namonte Basin, Ankilimiavotse, Namonte, and Ankilitelo (population < 200) are Mikea communities that resisted forced resettlement by organizing around powerful diviner-healers, and therefore remain more culturally traditional (Tucker 2003). Behisatse, Antaolandambo, and Montobe (population ca. 30) are forest camps where individuals from Vorehe and Namonte cultivate swidden fields, herd livestock, and forage for wild tubers and small game. The elders of Antaolandambo were visiting their friends at Montobe on the day the historical matrix was conducted, so these communities are lumped together.

Most participants self-identified as Mikea and resided at least part of the year in the forest. The villages of Andranodehoke and Marolinta are exceptions, being

Table 1 Summary data for the 14 field sites

Site	Number of participants	Major social identity of participants	Reside permanently at this site?	Activities included in matrix exercise
Village of Vorehe				
Vorehe Avaratse	3	Mikea	Part-time in forest	Mz, Mn, Ov, Tg, Tm, Ho, Te
Ankilimalaimbola	5	Mikea	Part-time in forest	Mz, Mn, Ov, Tg, Tm, Ho, Te
Ankiliraike	5	Mikea	Part-time in forest	Mz, Mn, Tm, Ho, Tb, Te
Ambaniandro Qtr.	5	Merina, Vezo, Mikea	Yes	Mz, Mn, Ov, Tg, Tm, Ho, Of
Other savanna villages				
Marolinta	7	Masikoro, Tesaka	Yes	Mz, Mn, Rc, Lf
Andranodehoke	6	Masikoro	Yes	Mz, Rc, Lf
Mañono	25	Mikea	Yes	Mn, Rc, Sg, Sp, Mg, Bl, Ho, Lf
Coastal villages				
Afeza	12	Mikea	Yes	Mz, Mn, Sg, Sp, Mg, Ho, Of, Cr
Ankindranoke	5	Mikea	Yes	Mz, Mn, Wm, Sp, Mg, Of, Cr, Oc, Sc
Namonte Basin villages				
Ankilimiavotse	3	Mikea	Part-time in forest	Mz, Mn, Bl, Ho, Tm, Tn, Lf
Namonte	6	Mikea	Part-time in forest	Mz, Ov, Bl, Bb, Ho, Lf
Ankilitelo	12	Mikea	Part-time in forest	Mn, Sp, Bl, Ho, Tm, Tn, Lf
Forest camps				
Montobe/ Antaolandambo	2	Mikea	Part-time in villages	Mz, Ov, Ho, Tn
Behisatse[a]	5	Mikea	Part-time in villages	Mz, Mn, Ov, Ho, Tm, Tn

[a] Behisatse is a pseudonym.

Agricultural Activities; Mz = maize; Mn = manioc; Rc = rice; Sg = sugarcane; Wm = watermelon; Sp = sweet potato; Mg = mango; Foraging and Fishing Activities; Ov = ovy (*Dioscorea acuminata*); Bl = balo (*D. acuminata*); Bb = babo (*D. bemandry*); Tg = tavolo (*Tacca pinnatifida*) in ground; Tm = tavolo in market; Tb = tubers generally; Ho=honey; Tm = tambotrike (*Echinops telfairi*); Tn = tandrake (*Tenrec ecaudatus*); Te = tenrecs generally; Lf = lake fish; Of=ocean fish; Cr=crabs; Oc=octopus; Sc=sea cucumbers

mostly Masikoro with a Tesaka minority who migrated from eastern Madagascar in the 1920s. The “Ambaniandro Quarter” of Vorehe is home to the three sons of a Merina man who came to Vorehe from Antananarivo in the 1920s to buy silk from Mikea. The Merina men married Vezo women, and most of their children consider themselves Mikea.

Rainfall

Indian Ocean cyclones, Antarctic winds, and El Niño events conspire to give Madagascar one of the most extreme and variable climates in the world (Wright 1999). Rainfall data for the Mikea Forest region are available from several sources.

The author managed self-logging pluviometers at Vorehe, Behisatse, Ankilimiavotse, and Ankindranoke from October 1997 through June 2000. The cotton exporting company HASYMA has longitudinal rain data from weather stations in the villages of Andranovorindrengatake, Ampasikibo, and Ankililoake (Fig. 2).

Rainfall is highly seasonal. November through March is the locally recognized rainy season (*litsake*), during which 87 to 90% of precipitation occurs. The timing of the beginning of the rainy season is unpredictable. Ten years of data from Ampasikibo show that the first day with more than 10 mm rainfall varies from 25 September to 4 December. Mikea consider the year to begin with the first rains (*lohatao*). Throughout this paper, a year is defined as beginning October 1 (so, 1999 refers to October 1998–September 1999).

Rainfall is spatially and interannually variable. Yearly rainfall at Ampasibo and Ankililoake correlate significantly (Pearson's $r = 0.778$, $p = 0.014$, $N = 9$), but neither significantly predicts rainfall at nearby Andranovorindrengatake (vs Ampasikibo, $r = 0.672$, $p = 0.143$, $N = 6$; vs Ankililoake, $r = 0.577$, $p = 0.231$, $N = 6$). Rainfall is generally lighter on the coast and forest and heavier further east in the savanna. In 1998, a coastal site (Ankindranoke) received 271 mm, a forest site (Ankilimiavotse) received 104 mm, and a savanna site (Ampasikibo) received 651 mm. Illustrating interannual variability, in 1999 these same sites received 642 mm, 826 mm, and 1,495 mm, respectively. All three HASYMA sites agree that 1998 was the driest year of the past decade whereas 1999 was the rainiest.

Economic Activities

The two most important agricultural crops are maize (*Zea mays*), grown in slash-and-burn fields, and manioc (*Manihot esculenta*), grown in permanent savanna fields or, less often, in slash-and-burn fields or lakebed gardens. Watermelon (*Citrillus* sp.) and sweet potatoes (*Ipomoea batatas*) are often intercropped with maize and manioc, respectively. Rice (*Oryza sativa*) is grown in labor-intensive irrigated fields along the water systems of the Iovy and Befandrea creeks and in the Mañono lakebeds. Sugarcane (*Saccharum* sp.) is a major cash crop in Mañono and along the coast.

Mikea forage for a wide variety of wild tubers and small game, as well as honey. Key among wild tubers are three varieties of *Dioscorea* yams. Mikea distinguish between *ovy* and *balo*, although these hardy tubers are similar in appearance and may be varieties of the same species, *Dioscorea acuminata* (Sorg 1996). The third yam is *babo*, which Fanony (1986) identifies as *Dioscorea bemandry. Babo*, which has a texture similar to watermelon, is 95% water and is valued primarily for sating thirst. A fourth wild tuber, the potato-sized *tavolo* (*Tacca pinnatifida*), is processed into flour to remove toxins and consumed as porridge.

The most important small game prey during the study period were two species of tenrec: the small-bodied (60–120 g) *tambotrike* (*Echinops telfairi*) and the large-bodied (600–1,400 g) *tandrake* (*Tenrec ecaudatus*). Tenrecs (misnamed "African hedgehogs" in the US pet market) are insectivorous mammals that feed during the short rainy season and then estivate (summer-hibernate) in burrows in trees or beneath the ground during the 9-month dry season.

Freshwater and ocean fish are captured with line and net. Mikea on the coast gather crabs and sea cucumbers, especially *Holothuria scabra*, in the intertidal zone, and hunt octopus in deeper waters. Sea cucumbers are never eaten, but are sold to middlemen who traffic them to East Asian markets.

Method

The objective of the historical matrix participatory exercise is to reveal shared perceptions of change over time (Freudenberger 1994, 1996). I adapted this methodology to map out perceptions of interannual variation and covariation. Participants were whoever had assembled to socialize with the field team during the heat of the day or around the campfire at night, regardless of age and sex, during fieldwork in May and June 1999. The matrix was clearly delineated on the ground using playing cards; each card, lying face-down on the ground, was a cell in the grid (Fig. 3). The exercise began when a Malagasy colleague laid five cards in a column and told the assembly that the cards represent the past 5 years, 1999 through 1995. We asked the crowd to make a pile of sand on each card representing how much rain fell in each year. The actual task was accomplished by a spokesperson of our choosing, usually someone junior (thus obligated to listen to the assembly). The assembly discussed the appropriate quantity of sand to deposit on each card. Once the rainfall column was completed, a second column of five cards was laid into place. At most sites, the second column represented maize harvest. Participants were instructed to indicate the quantity of maize production in each year by placing a pile of sand on each card. This was repeated in subsequent columns for other foraging, fishing, and farming activities important for the community, until we ran out of pertinent activities, cards, or participants' attention.

We limited the time depth of the exercise to 5 years because in the Mikea dialect of Malagasy there is a specific word for each of the past 4 years (*faizao*, *faity*, *fairoe*, *fairoa*), and one may unambiguously speak of the year before the fourth year (*alohan-fairoa*), but there is no clear way to talk about a sixth or seventh year in the past. At Andranodehoke, people insisted that they could not remember 1995, so their matrix contained only four rows.

As the participants discussed the appropriate quantity of sand to place on each card, they made narrative statements justifying their decision. These qualitative

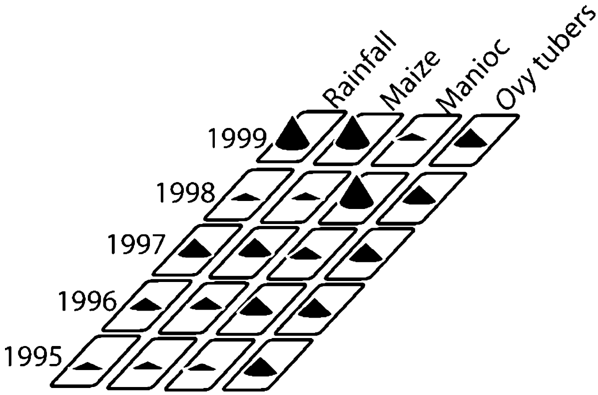

Fig. 3 The historical matrix exercise. In these hypothetical results, because rainfall and maize are ranked identically, Spearman's rho = 1.000 ($N = 5$). Manioc is ranked in perfect inverse order (rho = −1.000). *Ovy* does not vary interannually

statements are classified into three categories: statements of quantity ($N = 22$), statements of events ($N = 28$), and statements of rules ($N = 45$; Table 2). Statements of quantity included expressions of size, abundance, or amount, such as *maro* (a lot) and *kelikelike* (very little). Statements of events recall specific historical occurrences. Two statements label particular years as bad years or *baintao*, literally, "wounded

Table 2 Qualitative responses: Statements of events and rules

Qualitative statements	
Events ($N = 30$)	
Related to grasshopper abundance: year grasshoppers arrived, year grasshoppers were destroyed by pesticides, etc. (6)	
Year of crop loss to grasshoppers (6)	
Year of cyclone, extreme flooding (4)	
Year of crop loss or damage due to unspecified reason (3; Maize = 2, watermelon = 1)	
Year we were forced to purchase food (2)	
Year we planted too little (2; maize = 1, sugarcane = 1)	
Baintao, "wounded year" (2)	
Year we marketed honey (1)	
Year sweet potato crop was destroyed by cattle (1)	
Year new rice pest arrived (1)	
Year we grew maize up north (1)	
Year we foraged for *ovy* out west (1)	
Rules ($N = 45$)	
Varies from year to year (not necessarily in response to rainfall)	Maize (1)
	Tandrake (1)
	Honey (1)
Does not vary interannually	Ovy (1)
	Tambotrike (1)
	Amount of ocean fish sold in Vorehe Market (1)
	Crabs (1)
	Manioc (1)
Varies positively with rainfall	Ovy (4)
	All crops (2)
	Maize (2)
	Maize grown on sandy soil (1)
	Tandrake (2)
	Ocean fish (2)
	Manioc grown on sand (1)
	Sweet potatoes grown on sand (1)
	Crabs (1)
	Mangoes (1)
Varies negatively with rainfall	Manioc (5)
	Rice (2)
	Honey (1)
	Tavolo (1)
	Frequency at which Mañono residents forage for balo (1)
	Frequency at which Mañono residents forage for honey (1)
	Sugarcane (1)
	Sea cucumbers (1)
Other	During *baintao* there is lots of tavolo in the Vorehe market (2)
	In dry years, those who plant maize *before* the first rains have greater harvests (1)
	Ovy is not affected by grasshoppers [indicating that more foraging occurs in years of high pest damage] (1)

years." Statements of rules posit cause-and-effect relationships: *lafa be ora*, *tsy misy tantely* (when there is much rain, there is no honey), or *halam-balahazo ora!* (manioc hates rain).

Responses were also measured quantitatively. Once the entire grid was completed, the volume of the sand on each card was measured by pouring the sand into a graduated cylinder (a plastic film canister with millimeter gradations). Because the cardinal sandpile volumes are unlikely to be a precise representation of nature or people's perceptions, all statistical tests use ordinal values, the rank of the five sandpiles within the column (four at Andranodehoke). Analyses consist of nonparametric tests of association appropriate for small sample sizes. Spearman's rank-order correlation coefficient (rho) is used to measure bivariate association. Kendall's Coefficient of Concordance (W) measures association among three or more ranked independent variables. The W coefficient ranges from zero (perfect disarray) to 1 (perfect concordance; Hirsch and Riegelman 1992: 257–260; Sokal and Rohlf 1995: 600–601).

Results and Discussion

Prediction 1: Rainfall-Activity Correlations

The first prediction is that if Mikea follow the rule-of-thumb to combine activities that covary positively and negatively with rainfall, participants at all sites should consistently identify positive and negative covariation in the matrix exercise. Participants at a site identified covariation either explicitly, by stating a causal rule: 26 of the 45 rule statements specifically link rainfall positively or negatively with an activity outcome, or they identified covariation by making their five sandpiles for rainfall and for a particular activity correlate highly (high Spearman's rho). Taking each site individually, I tested for correlation between rainfall and each activity, conducting a total of 90 rainfall-activity correlations. For each test, $N=5$ corresponding to the 5 years of observations (rows in the matrix), except for Andranodehoke ($N=4$). A perfect positive correlation indicates that participants ranked rainfall over the 5 years in the same order as they ranked the activity outcome; a perfect negative correlation is the inverse order.

Figure 4 summarizes the qualitative and quantitative evidence. Because there are limited ways that two sets of five cards can be ranked, there are a discrete number of resulting correlation coefficients. The range of correlation coefficients and probability values are displayed in Fig. 4, as a frequency distribution of outcomes. For the sake of discussion, a high positive correlation is defined as rho ≥ 0.895, a high negative correlation as rho ≤ -0.895 ($p \geq 0.041$), and coefficients ≤ 0.200 and ≥ -0.200 indicate no interannual variation.

For all activities except honey and sugarcane, there is general agreement among sites as to whether the direction of the correlation with rainfall is positive (maize, sweet potato, watermelon, mango, all tubers, *tandrake*, freshwater and ocean fish, crabs), negative (manioc, rice), or neither (*tambotrike,* octopus, sea cucumbers). Some specific activities are described below.

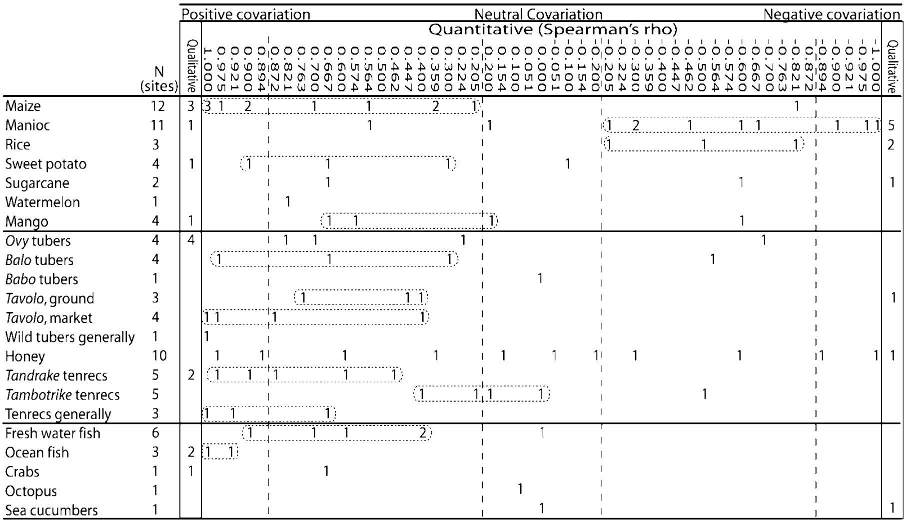

Fig. 4 Summary of qualitative and quantitative evidence for positive and negative rainfall-activity covariation

Maize

Six out of 12 sandpile correlations between rainfall and maize were highly positive, indicating wide agreement that maize is productive during years of heavy rainfall. In the spirit of paying attention to nonoccurrences, one may well ask why *only* half were highly positive. Statements of events from the other six sites recount maize failures owing to grasshopper predation, suggesting that rainfall is not the only important causal variable.

Manioc and Rice

The only clear negative covariations revealed by the exercise are those between rainfall and manioc/rice. Informants insisted that it is easier to control water in dry years. In 1999, heavy wind and rains had flooded many fields, blown over manioc stems and rotted tubers, and fouled rice irrigation schemes. At Afeza, participants said their manioc is *more* productive during years of heavy rainfall, but they specified that this rule applies only to manioc grown in slash-and-burn fields on well-drained, sandy soil, as opposed to the permanent savanna fields, for which they confirmed the negative covariation.

Wild Ovy Tubers

The four positive qualitative statements for wild *ovy* seem at odds with the absence of high positive correlations. The Antaolandambo and Montobe elders stated that although rainfall does encourage *ovy* growth, high spatial variation in rainfall means that there are bountiful patches of *ovy* somewhere in the forest every year. In effect, *ovy* is interannually invariant.

Tenrecs

Tandrake are perceived to covary positively with rainfall, while *tambotrike* are purportedly interannually invariant (the elders at Antaolandambo-Montobe went to considerable effort to place exactly equivalent sandpiles on each card). The difference may have to do with how they are captured. *Tambotrike* are gathered from their burrows while in torpor during the dry season. In contrast, only a few, highly skilled individuals know how to locate estivating *tandrake;* this tenrec is usually hunted with dogs during the rainy season while they are active. A longer rainy season would mean more chances to catch *tandrake*.

Marine Fish

Participants at both coastal sites acknowledged positive covariation between rainfall and fishing in their sandpile ranks and with explicit statements. At both sites, people stated, *mino rano koa ñy fia* (fish drink water, too). The assertion is that during years of heavy rainfall, the salinity of the shallow bays of Fañemotse and Tsingilofilo is reduced, and ocean fish go there to drink. An alternative explanation is that heavy rainfall washes nutrients into the bays, benefiting the microorganisms upon which fish feed.

Summary

Given the small number of negative correlations identified, it seems unlikely that Mikea match a negatively correlating activity for each positively correlating activity. It does suggest that manioc and rice have special value in Mikea portfolios (one man described his portfolio as a “marriage” between maize and manioc). Perhaps a more realistic rule of thumb is to combine positive, negative, and non-varying activities (particularly *ovy* and *tambotrike*) into a portfolio.

Prediction 2: Accuracy of Rainfall-Activity Correlations

To test the accuracy of the rainfall-activity covariations identified in the matrix one would ideally need many years of production data. Such data do not currently exist. Some production data (maize and *ovy*) and market data were collected in 1998 and 1999; because they were the driest and rainiest years (respectively) in the preceding 10, they provide suggestive evidence of the effect of rainfall on economic outcomes.

Maize yield was surveyed in 247 slash-and-burn fields by counting the number of ears in a typical 5 m^2 plot (Tucker 2001). In 1998, one-third of fields (10 of 32) reported total crop loss. In 1999, only 3% (7 of 215) harvested nothing. Excluding the zero-yield cases, the mean harvest in 1998 was 616 kg/ha, and in 1999 the mean was 1040 kg/ha. This significant difference ($t = -3.553$, $\mathrm{df} = 24$, $p = 0.002$) suggests that maize is more productive in years of heavy rainfall.

Wild *ovy* returns were recorded in a foraging event log at the forest camp of Behisatse (Tucker 2001; Tucker and Young 2005). Mean return rates in 1998 were 1.68 kg/h (1,748 net kcal/h, $N = 109$); in 1999 they were similar at 1.82 kg/h (1,909 net kcal/h, $N = 19$). The difference is not significant ($t = -0.554$, $\mathrm{df} = 126$, $p = 0.581$). As the Antaolandambo-Montobe elders reported, *ovy* may in effect be interannually invariant.

Table 3 Number of vendors selling each product during eight Wednesday markets in the village of Vorehe during March–June 1998 (the driest year in the past decade) and March–June 1999 (the rainiest year in the past decade)

Product	1998	1999
Maize	212	341
Manioc	82	54
Rice	284	168
Sweet potato	20	37
Sugarcane	17	17
Watermelon[a]	0	0
Mango[a]	0	0
Ovy and *balo* tubers	121	199
Babo tubers	0	1
Tavolo flour	6	16
Honey	22	21
Tandrake tenrecs	5	16
Tambotrike tenrecs	24	31
Freshwater fish	0	1
Ocean fish	200	255
Crabs	5	14
Octopus	15	46

[a] Watermelon and mango are not in season from March through June.

Table 3 displays the number of vendors for each product during eight Wednesday markets in the village of Vorehe, for the same period (March through June) in 1998 and in 1999. This period immediately following the rainy season is when most crops are harvested. Consistent with the covariations reported above, there were more vendors of manioc and rice in 1998, and more vendors selling maize, sweet potato, *tandrake,* and ocean fish in 1999.

Prediction 3: Use of Memory versus Use of Theory in Matrix Exercise

If participants used memory-recall (individual learning) to complete the matrix, their comments should primarily be statements of events—mnemonics to jog their memory. As stated above, the majority of statements were statements of rules ($N = 45$). The presence of many rules, consistently stated in different communities (sometimes with nearly identical phrases), suggests that Mikea do have covariation ethnotheories. However, participants often made event statements ($N = 28$) to justify the size of sandpiles for particular years. Informants treated the historical matrix exercise as *both* a memory task and an ethnotheory task.

Prediction 4: Accuracy of Memory of Rainfall

The next prediction is that if Mikea are capable of accurately perceiving and remembering rainfall over the course of 5 years, participants should rank annual rainfalls in the same order as would data from local weather stations. Because rainfall was not measured in the forest during 1995–1997, this analysis uses data from the three HASYMA sites. Data from the three HASYMA sites rank annual rainfall concordantly (Kendall's $W = 0.82$), but not in exactly the same order. All three stations ranked 1999 first (the rainiest) and 1998 last (the driest); their disagreement about the ranking of 1997, 1996, and 1995 reflects spatial variation in rainfall.

At no matrix site did participants rank rainfall in the same order as data from any of the three HASYMA sites. Participants at 13 of the 14 sites successfully ranked 1999 the rainiest year, but only 5 recognized 1998 as the driest.

I tested for correlation between rainfall as reported in the matrix (at 13 sites; Andranodehoke is excluded from this analysis since $N=4$ years) and actual rainfall (at 3 sites). For the 39 correlation coefficients, the mean coefficient was 0.430 (mode = 0.400, $p=0.505$); only 4 surpass traditional significance thresholds (in all four cases, rho = 0.900, $p=0.037$). Mikea memory of interannual rainfall is not concordant with empirically measured rainfall data.

Prediction 5: Internal Consistency of Memory of Rainfall

The previous analysis is inappropriate if spatial variability is sufficiently great so that rainfall at the HASYMA sites does not correspond to rainfall at specific forest and coastal sites. An alternative way to test the accuracy of memory of past rainfall is to examine whether there is greater concordance among sites located close to each

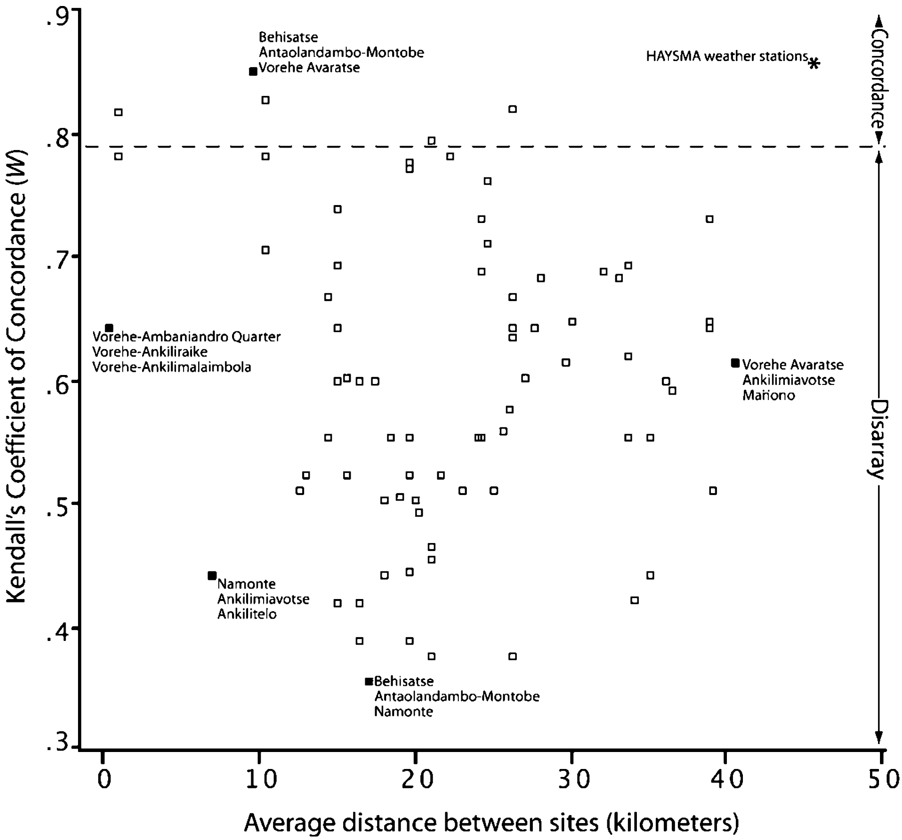

Fig. 5 Scatterplot of all 78 possible combinations of three matrix sites, by geographic proximity (average distance, kilometers) and similarity of recall of past annual rainfall (Kendall's Coefficient of Concordance)

other, such as the four Vorehe neighborhoods or the three Namonte Basin villages, than among sites located farther from one another.

I calculated Kendall's Coefficient of Concordance for the rainfall rankings of all 78 possible combinations of three matrix sites. The mean coefficient for all 78 tests was 0.60. A chi-square test commonly accompanies Kendall's W to test the null hypothesis that the association among variables is significantly greater than zero (Hirsch and Riegelman 1992: 257–260). Assuming $p < 0.05$, any W less than 0.79 indicates disarray ($\chi^2 < 9.488$). In total, 73 of 78 combinations are in disarray.

Kendall's W is plotted by average distance (in kilometers) between sites for all 78 combinations of three sites (Fig. 5). The distribution is markedly nonlinear ($R^2 = 0.004$, $F = 0.283$, $p = 0.596$). The three closest sites are the three Vorehe neighborhoods, which are spatially contiguous (Ambaniandro Quarter, Ankiliraike, Ankilimalaimbola). Residents at these sites should remember rainfall identically. Their concordance is greater than the average ($W = 0.64$). However, the three sites that are furthest away from each another (Vorehe Avaratse, Ankilimiavotse, Mañono) are almost equally concordant ($W = 0.62$). The greatest concordance among any three sites belongs to Behisatse, Antaolandambo-Montobe, and Vorehe Avaratse ($W = 0.85$). These four communities interact frequently and have common ties in Vorehe and Namonte. The lowest concordance is between Behisatse, Antaolandambo-Montobe, and Namonte ($W = 0.35$). The three Namonte Basin villages, connected by short geographical and genealogical distances, and frequently interacting socially, ranked rainfall in disarray ($W = 0.44$). There does not appear to be any internal consistency in memory of past rainfall. Sites located near each other do not rank rainfall more similarly than sites distant from one another.

Conclusions

The preceding analyses demonstrate that Mikea share a collective perception for how most of their food-producing activities covary with rainfall. They may not consciously follow a rule-of-thumb quite as explicit as "mix rain-loving and rain-hating activities." But the knowledge that maize, sweet potatoes, *tandrake*, and ocean fish are bountiful in rainy years whereas manioc and rice are productive in dry years, and *ovy* tubers and *tambotrike* are productive in all years, may be a significant tool for managing rainfall-related risk. This analysis suggests that manioc and rice are particularly valuable activities because negatively covarying activities are comparatively rare. Interannual variance for wild honey and its significance for the portfolio is not explained.

Mikea share covariation ethnotheories. This was demonstrated in the qualitative rule statements, some of which were phrased nearly identically at different sites. However, Mikea also attempt to judge covariation individually based on their memory of past observations. Had participants relied only on rules for completing the matrix, all the sandpiles should have been highly correlated. Most correlations were low.

The covariant relationships Mikea perceive appear to be accurate. Existing production and market data confirm the rainfall-activity covariations identified in the matrix. However, memory of rainfall over the past 5 years is highly inaccurate. Individual ability to evaluate interannual differences in rainfall is apparently quite poor. They also do not appear to have shared memory about the local history of rainfall, as demonstrated by the fact that residents of the same village (Vorehe) rank the past 5 years of rainfall discordantly.

These findings are consistent with both Boyd and Richerson's (1988, 2001) prediction that individual learning should be favored in stochastic environments, and Nisbett and Ross's (1980) argument that individual learning is ineffective when memory requirements are high. There are great benefits to individual learning in the Mikea case. Diversification is costly, so it is valuable to know how few activities the household must practice to reduce risk. Individuals attempt to observe and remember rainfall and economic outcomes over the course of several years, but their actual ability to remember past events is probably compromised by the long time separating observations, their recall is biased by extreme events, they judge from a small sample of observations, and they use simplified heuristics. In their daily lives, Mikea do something akin to what they did in the historical matrix. They discuss their individual observations of the present and their memory of the past with each other. As individual observations are pooled and transmitted, ethnotheory emerges. Ethnotheory and its proscriptions for behavior gain in consistency and are continually perfected by individual perception, even as individual perception remains limited. This suggests that traditional environmental knowledge may be accurate despite individuals' perceptive limits.

Acknowledgement Several individuals deserve thanks for the roles they played in the conception of this paper. As part of his dissertation research, James Yount arranged for Karen Freudenberger to train our Malagasy colleagues Tsiazonera and Jaovola Tombo in participatory methods including the historical matrix in Fianarantsoa, Madagascar, in 1998. During my dissertation follow-up project in 1999, Tsiazonera and Jaovola taught me the historical matrix exercise, and we decided that it could be used to reveal covariation perception. They, along with Gervais Tantely and Tsimitamby, assisted with data collection. Special thanks to all our research participants for their patience. HASYMA kindly provided data from their weather stations and official permission to publish these data. Thanks to the following for comments on previous drafts: James Yount, Larry Kuznar, Joe Henrich, Lexine Trask, Tammy Watkins, Lisa Chaudhari, and the anonymous reviewers. Field research was funded by a National Science Foundation Dissertation Improvement Grant.

References

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago: University of Chicago Press.

Boyd, R., & Richerson, P. J. (1988). An evolutionary model of social learning: The effects of spatial and temporal variation. In T. R. Zentall & B. G. Galef (Eds.), *Social learning: Psychological and biological perspectives* (pp. 29–48). Hillsdale, NJ: Lawrence Erlbaum Associates.

Boyd, R., & Richerson, P. J. (2001). Norms and bounded rationality. In G. Gigerenzer & R. Selten (Eds.), *Bounded rationality: The adaptive toolbox* (pp. 281–296). Cambridge, MA: MIT Press.

Cashdan, E. (1992). Spatial organization and habitat use. In E. A. Smith & B. Winterhalder (Eds.), *Evolutionary ecology and human behavior* (pp. 237–266). New York: Aldine de Gruyter.

Chapman, L. J. (1967). Illusory correlation in observational report. *Journal of Verbal Learning and Verbal Behavior, 6*, 151–155.

Fanony, F. (1986). A propos des Mikea. In C. P. Kottak, J.-A. Rakotoarisoa, A. Southall & P. Vérin, (Eds.), *Madagascar: Society and history* (pp. 133–142). Durham: Carolina Academic Press.

Freudenberger, K. S. (1994). *Tree and land tenure: Rapid rural appraisal tools.* Community Forest Field Manual 4. Rome: Food and Agriculture Organization of the United Nations.

Freudenberger, K. S. (1996) *The use of Rra to inform policy: Observations from Madagascar and Guinea.* PLA Notes 26: Participation, Policy, and Institutionalization. University of Sussex.

Harpending, H., & Davis, H. (1977). Some implications for hunter–gatherer ecology derived from the spatial structure of resources. *World Archaeology, 8*, 275–286.

Henrich, J., & McElreath, R. (2003). The evolution of cultural evolution. *Evolutionary Anthropology, 12*, 123–135.

Hirsch, R. P., & Riegelman, R. K. (1992). *Statistical first aid: Interpretation of health data*. Washington: Blackwell Science.

Hunn, E. S., Johnson, D., Russell, P., & Thornton, T. F. (2003). Huna Tlingit traditional environmental knowledge, conservation, and the management of a "wilderness" park. *Current Anthropology, 44*, s79–s103.

Inhelder, B., & Piaget, J. (1958) *The growth of logical thinking from childhood to adolescence*. New York: Basic.

Johannes, R. E. (1989). *Traditional environmental knowledge: A collection of essays*. Cambridge: World Conservation Union.

Kelley, H. H. (1973). The process of causal attribution. *American Psychologist, 28*, 107–128.

Markowitz, H. (1952). Portfolio selection. *Journal of Finance, 7*, 77–91.

Nisbett, R., & Ross, L. (1980). *Human inference: Strategies and shortcomings of social judgement*. Englewood Cliffs, NJ: Prentice-Hall.

Orlove, B. S., Chiang, J. C. H., & Cane, M. A. (2002). Ethnoclimatology in the Andes. *American Scientist, 90*, 428–435.

Shaklee, H., & Mims, M. (1981). Development of rule use in judgments of covariation between events. *Child Development, 52*, 317–325.

Shaklee, H., & Mims, M. (1982). Sources of error in judging event covariations: Effects of memory demands. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 208–224.

Shaklee, H., & Tucker, D. (1980). A rule analysis of judgments of covariation between events. *Memory & Cognition, 8*, 459–467.

Sokal, R. R., & Rohlf, F. J. (1995). *Biometry*. New York: W. H. Freeman.

Sorg, J.-P. (1996). Vernacular and scientific names of plants of the Morondava region. *Primate Report, 46*(1), 339–346.

Tucker, B. (2001). *The behavioral ecology and economics of variation, risk, and diversification among Mikea forager–farmers of Madagascar*. Ph.D. dissertation, University of North Carolina at Chapel Hill.

Tucker, B. (2003). Mikea origins: Relicts or refugees? *Michigan Discussions in Anthropology, 14*, 193–215.

Tucker, B., & Young, A. G. (2005). Growing up Mikea: Children's time allocation and tuber foraging in Southwestern Madagascar. In B. S. Hewlett & M. E. Lamb (Eds.), *Hunter–gatherer childhoods* (pp. 147–171). New Brunswick, NJ: Transaction.

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology, 5*, 207–232.

Tversky, A., & Kahneman, D. (1974). Judgement under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.

Ward, W. D., & Jenkins, H. M. (1965). The display of information and the judgment of contingency. *Canadian Journal of Psychology, 19*, 231–241.

Williams, G. C. (1966) *Adaptation and natural selection*. Princeton: Princeton University Press.

Winterhalder, B. (1986). Diet choice, risk, and food sharing in a stochastic environment. *Journal of Anthropological Archaeology, 5*, 369–392.

Winterhalder, B. (1990). Open field, common pot: Harvest variability and risk avoidance in agricultural and foraging societies. In E. Cashdan (Ed.), *Risk and uncertainty in tribal and peasant economies* (pp. 67–87). Boulder: Westview Press.

Winterhalder, B., & Smith, E. A. (1992). Natural selection and decision-making: Some fundamental principles. In E. A. Smith & B. Winterhalder (Eds.), *Evolutionary ecology and human behavior* (pp. 25–60). New York: Aldine de Gruyter.

Wright, P. C. (1999). Lemur traits and Madagascar ecology: Coping with an island environment. *Yearbook of Physical Anthropology, 42*, 31–72.

Yount, J. W., Tsiazonera, & Tucker, B. (2001). Constructing Mikea identity: Past or present links to forest and foraging. *Ethnohistory, 48*, 257–291.

Bram Tucker received his Ph.D. in anthropology at the University of North Carolina in Chapel Hill in 2001. He has conducted ethnographic research on economic, ecological, and ethnographic topics in southwestern Madagascar since 1996. His current research explores risk and time preferences in portfolio composition decisions among Mikea, Masikoro, and Vezo.