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Folkecology and commons management in the Maya Lowlands

(cognitive models/commons tragedy/culture consensus/social networks/sustainable agroforestry)

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ABSTRACT **Three groups living off the same rainforest habitat manifest strikingly distinct behaviors, cognitions, and social relationships relative to the forest. Only the area's last native Maya reveal systematic awareness of ecological complexity involving animals, plants, and people and practices clearly favoring forest regeneration. Spanish-speaking immigrants prove closer to native Maya in thought, action, and social networking than do immigrant Maya. There is no overriding "local," "Indian," or "immigrant" relationship to the environment. Results indicate that exclusive concern with rational self-interest and institutional constraints do not sufficiently account for commons behavior and that cultural patterning of cognition and access to relevant information are significant predictors. Unlike traditional accounts of relations between culture, cognition, and behavior, the models offered are not synthetic interpretations of people's thoughts and behaviors but are emergent cultural patterns derived statistically from measurements of individual cognitions and behaviors.**

Neotropical forests and their resident cultures are disappearing at alarming rates, owing in part to non-native actors having increasingly open access to forest resources (1). The Lowland Maya region is a prime example. A central problem concerns conflicting use of common resources by different groups exploiting the same habitat (2). Study of "the tragedy of the commons" indicates that individual calculations of rational self-interest collectively lead to a breakdown of the resource base in the face of immigration (3): It is irrational to continue to act to sustain a diminishing resource that others increasingly deplete. But narrow concern with utility-bounded rationality does not sufficiently account for cultural differences in environmental behavior (4).

To bring a new perspective to the commons debate and to the human dimensions of environmental change, we combine techniques from anthropology and psychology to explore "folkecology": how people understand and utilize interactions between plants, animals, and humans. Ethnobiological studies reveal universal principles that reflect the mind's ability to capture and organize perceptually salient species in taxonomies (5). But this leaves aside important insights into how people cognitively model species relationships in ways relevant to environmental behavior (6).

We also analyze social networks in relation to cognition to track lines of ecological learning and information flow within and between cultures. Successful environmental management increasingly involves diverse groups with distinctive views of nature. Thus, understanding the ways in which local cultural boundaries are permeable to the diffusion of relevant knowledge can offer important clues to success with more global, multicultural commons.

Finally, our findings bear on the historical relationship of Lowland Maya to their tropical limestone environment, including anthropogenic effects on biodiversity patterning. Study of contemporary Maya thought and behavior has informed attempts to understand how these ancient people endured (7), but operationally reliable data are rare (8). Our research helps to fill the void.

Different Actors on a Common Stage

Our studies concern three cultural groups in the same municipality in Guatemala's Department of El Petén: native Itzaj Maya, Spanish-speaking immigrant Ladinos, and immigrant Q'eqchi' Maya. Each group founded, and predominates in, a distinct locality: Itzaj in the town of San José, Ladinos in the settlement of La Nueva San José, and Q'eqchi' in the hamlet of Corozal. Interviews were in Itzaj, Spanish, and Q'eqchi' for each community, respectively.

In 1960, the military government opened Peten (one-third of Guatemala's territory) to colonization. Satellite imagery indicates 40% of Peten's quasi-rainforest cover was destroyed and 10% was degraded between 1960 and 1990, as population increased from 21,000 to >300,000 (9). In 1990, under a "debt-for-nature" swap, Guatemala's government included remaining forests north of latitude 17°10′ in a United Nations-sponsored Maya Biosphere Reserve. Our three groups lie within the Reserve's official "buffer zone" between that latitude and Lake Peten Itza to the south.

San José has 1,789 habitants. Most identify themselves as Itzaj, although only a minority speak the native tongue. Itzaj represent the last Lowland Maya with demonstrable ties of genealogy (10) and practice to pre-Columbian civilization in Peten's northern forests (11), where population once exceeded the region's current level by an order of magnitude (12). Nearly all 625 inhabitants of neighboring La Nueva are Ladinos (mixed European and Amerindian descent). Most drifted into the area in the 1970s as nuclear families stemming from various towns of southeast Guatemala. Corozal was settled at the same time by Q'eqchi' speakers, a Highland Maya group. Although Q'eqchi' also filtered in as nuclear families, they migrated in two waves that transplanted partial Highland communities to Corozal: (*i*) directly from towns in the vicinity of Coban (capital of the Department of Alta Vera Paz due south of Peten) and (*ii*) indirectly from Alta Vera Paz via the southern Peten town of San Luis (home to a mixed community of Q'eqchi' and Lowland Mopan Maya). Most of the 395 inhabitants speak only Q'eqchi' (not mutually intelligible with Itzaj). The Q'eqchi' now comprise the largest and most linguistically isolated ethnic group in Peten (13).

Abbreviations: I, Itzaj Maya; L, Ladino; Q, Q'eqchi' Maya; M, milpa (swidden plot); G, guamil (fallow milpa); R, reserve (secondary forest).

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All groups practice agriculture and horticulture, hunt game, and extract timber and non-timber forest products for sale. Each household (about five persons) has usufruct on 30 manzanas (21.4 ha) of *ejido* land (municipal commons), paying yearly rent (2–4 quetzales = $0.30-$0.70) for each manzana cleared for swidden plots, known as *milpa,* whose predominant crop is maize. Yearly variation in crop patterning can be substantial, owing in part to microclimate and drastic rainfall fluctuation (e.g., at the height of growing season, July rainfall in Flores, Peten's capital, went from 121 mm in 1993 to 335 mm in 1996, and in nearby Tikal from 58 mm to 137 mm) [Guatemala Government Meteorological Institute (INSIVUMEH)]. People can hold plots in scattered areas and can change plots. Plots from all groups may abut. Hunting is tolerated on neighbors' plots, but access to another's crops and trees warrants sanction.

Agroforestry Practices

Although all groups share reliance on land and awareness of local species for survival, analyses of self-reported agroforestry practices showed striking differences (Table 1). Results cover a 3-year period among 12–16 informants for each group and include observational cross-checks in the third year. No significant group differences were found for age, family size, land available to cultivate, or per capita wealth. To capture the extent of forest destruction per cultivation cycle among our sample populations, let A = amount of land cleared per year, B = number of years land is continuously used, and C = number of years land is fallow. Let the extent of destruction be a weighted function $D = \alpha (A \times ((B + C)/B)) + \beta (A/(B + C))$. Assume the weights of α and β are equal (i.e., there is a trade-off between using less land over shorter fallow vs. more land over longer fallow); then, for Q'eqchi', D is 2.5× greater than for Ladinos and 4.0× greater than for Itzaj: $F(2, 41) = 17.75, P < 0.001$. Note that, independent of weighting, D (Q) > D (I), D (L), and that difference in burn frequency produces difference in destructiveness, independently of need for income. Remote sensing confirms rapid and extensive deforestation along Q'eqchi' migration routes into Peten (14) whereas Itzaj are regenerating plant and animal stocks depleted by others (15).

To corroborate cultural behavior patterns, after a 2-year lapse, we measured for 10 new informants from each group: plot sizes, species diversity, tree counts (minimum circumference >0.3 m at 1–1.5 m from ground), coverage (square meters of foliage for each tree crown), and soil composition (10-cm and 20-cm depths). For each informant, we sampled land held in usufruct in three locations: milpa, guamil (fallow milpa), and reserve (land uncultivated since initial clearance at the onset of usufruct). All locations were sampled after burning, planting, and weeding of a first-year milpa (when maize stalks reached 0.5–0.8 m before flowering). For each population, reserve samples were 1 ha, and guamil was 3 years old, on average. Our initial study suggested that, for all group measures relative to forest health and productivity, Itzaj ≥ Ladino ≥ Q'eqchi'; therefore, for the follow-up study, we report both two-tailed (Scheffe's $P < 0.05$) and one-tailed (Fisher probable least-squares difference $P < 0.05$) post hoc comparisons, the latter indicating marginal reliability in the predicted direction. Highly variable distributions of raw scores were normalized with a natural log transformation.

Table 1. ANOVA of reported swidden (milpa) practices

	n	Crops per year	Years of land use	Hectares cleared	Years fallow	Species per year
Itzaj (I)	16	2	2.3	1.6	4.7	7.8
Ladinos (L)	16	2	1.8	2.6	3.6	3.3
Q'eqchi' (Q)	12	1	1	4.1	3.3	3.6
Scheffe $P < 0.05$		I,L > Q	I,L > Q	I < L,Q	I > L,Q	I > L,Q

Again, Itzaj plant more species on average (9.7) than Ladinos (6.4) or Q'eqchi' (6.2) and clear less land yearly (2.0 ha) than Ladinos (2.4 ha) or Q'eqchi' (3.6 ha); however, an ANOVA of crop species/hectare as a function of group shows only a reliable difference between Itzaj and Q'eqchi': $F(2, 27) = 3.339, P < 0.05$. For all three groups, the most frequent crops are maize, then beans, then squash. Itzaj cultivate 43 species overall, Ladinos 26, and Q'eqchi' 23, implying a greater yearly species mix for Itzaj. We predicted that tree diversity would parallel crop diversity as a relative indicator of biodiversity: Itzaj average 9.0 species/ha, Ladinos 7.2, and Q'eqchi' 4.4. Number of tree species were analyzed with a 3 × 3 ANOVA using Group (I, Itzaj; L, Ladino; Q, Q'eqchi') and Location (M, Milpa; G, Guamil; R, Reserve). Results show effects of Group ($F(2, 81) = 10.48, P < 0.0001$; I, L > Q), Location ($F(2, 81) = 171.98, P < 0.0001$; R > M, G), and Group × Location ($F(4, 81) = 4.45, P = 0.003$; M: I > L, Q; G, R: I, L(marginal) > Q). As a relative measure of biomass, average tree cover shows the same pattern (Fig. 1), with effects of Group ($F(2, 81) = 6.17, P = 0.003$; I > Q, L(marginal)), Location ($F(2, 81) = 75.08, P < 0.0001$; R > M, G), and Group × Location ($F(4, 81) = 3.43, P = 0.01$; M: I(marginal) > Q; G: I > Q, L(marginal); R: I > Q). There is no reason to suppose group differences owe to base-rate differences in species frequency given the adjacency of parcels across groups.

For each group, soils are predominantly clays with block structures. These hold water and fix phosphorus but become unworkable and impede root growth during very dry and wet spells (frequent in Peten). Soils are moderately alkaline with no significant differences in pH or availability of organic matter (Table 2). Group differences are most apparent for (normalized) measurements of phosphorus and nitrates. Neither is abundant in the geological materials of limestone regions, and their availability represents limiting factors on life-support systems (16). Phosphorus and nitrate levels were analyzed by using Group × Location × Level ANOVAs. Phosphorus showed effects for Location ($F(2, 162) = 25.67, P < 0.0001$; M > G, R), Level ($F(1, 162) = 18.86, P < 0.0001$; 10 cm > 20 cm), and Group × Location ($F(4, 162) = 3.79, P = 0.006$; M: I, L > Q; R: L > I). Itzaj differ from Q'eqchi' in the upper milpa level ($P < 0.05$), where phosphorus is most abundant and useful to new plant growth. Overall, Itzaj have the highest milpa and lowest reserve scores, indicating greater phosphorus storage by plants in reserve with more available for release in milpa.

Nitrate levels show effects of Group ($F(2, 162) = 11.42, P < 0.0001$; I(marginally) > L > Q), Location ($F(2, 162) = 6.44, P = 0.002$; M > G), and Group × Location ($F(4, 162) = 2.87, P = 0.02$; M: I, L > Q; G: I > L, Q). For total land cleared (M + G), Itzaj differ marginally from Ladinos and significantly from Q'eqchi'. Interrelated factors allow Itzaj to enjoy relatively high phosphorus and nitrate levels in cultivated areas. Itzaj cultivate more varieties of nitrogen-fixing pole beans that climb maize stalks than do Q'eqchi' or Ladinos. Q'eqchi' and Ladinos weed only once shortly after planting; Itzaj weed a second time before maize has flowered and leave the weeds as mulch. Second weeding occurs when yearly rainfall is most intense. This favors

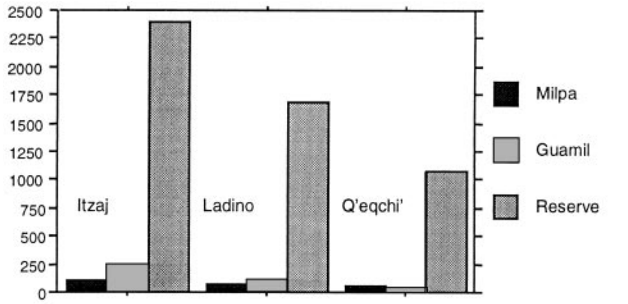

FIG. 1. Tree cover (square meters per hectare) as a function of ethnic group and location type

Table 2. Soil means for nitrates and phosphorus (micrograms per milliliter), other elements (milliequivalents per milliliter), pH, and percent organic matter

	Upper Milpa			Lower Milpa			Upper Guamil			Lower Guamil			Upper Reserve			Lower Reserve		
	Itzaj	Ladino	Q'eqchi'	Itzaj	Ladino	Q'eqchi'	Itzaj	Ladino	Q'eqchi'	Itzaj	Ladino	Q'eqchi'	Itzaj	Ladino	Q'eqchi'	Itzaj	Ladino	Q'eqchi'
Nitrates	78.3	37.8	33.6	64.9	39.1	20.4	56.4	18.4	13	31.8	13.5	12.4	27.9	39.6	27.37	23.3	30.3	27.97
P	19.1	17.2	7.3	8.14	11	4.44	7	3.27	6.18	1.91	2.37	2.17	1.95	5.99	2.87	1.79	2.92	2.03
K	0.46	0.29	0.47	0.23	0.21	0.29	0.25	0.22	0.37	0.12	0.17	0.28	0.19	0.22	0.24	0.08	0.12	0.19
Ca	34.9	38.8	38.3	44.5	46	56.1	39.4	40.1	42.5	48.7	53.5	52.8	39.2	32.4	46.86	55.6	44.1	59.42
Mg	2.66	2.36	2.24	3.72	2.2	1.7	2.24	2.03	2.41	1.7	1.85	2.03	2.18	3.35	1.73	2	3.21	2.17
pH	7.76	7.81	7.78	7.63	7.8	7.93	7.86	7.76	8.09	8.02	7.91	8.11	7.92	7.81	8	7.96	7.94	8.16
Percent organic matter	8.38	8.6	8.99	7.64	6.97	7.38	9.62	9	10.3	8.92	7.67	7.77	10.6	10.2	8.46	8.82	8.36	9.27

bacterial decomposition of mulch, which releases nitrogen (also phosphorus, potassium, and magnesium). Finally, Itzaj tend to light smaller and more dispersed fires to clear land and to protect valuable trees with firebreaks 2 m in radius. Less intense heat causes less volatilization of nitrogen.

A Group × Location × Level ANOVA also was performed on a composite of standardized scores for basic nutrient elements: P + (K + Mg − Ca). Because calcium is antagonistic to the fixing of potassium and magnesium, the composite score represents a balance of the available nutrient elements: phosphorus for root growth, potassium for stem strength, magnesium for photosynthesis, and calcium for cell formation. Results paralleled those of phosphorus for Location ($F(2, 162) = 15.15, P < 0.0001$; M > G, R), Level ($F(1, 162) = 34.10, P < 0.0001$; 10 cm > 20 cm) and Group × Location ($F(4, 162) = 4.02, P = 0.004$; M: I(marginally) > Q; R: L > I).

In sum, physical measurements corroborate reported behavior, indicating that Itzaj practices encourage a better balance between human productivity and forest maintenance than do immigrant practices. However, significant differences in immigrant practices reveal that immigrant Spanish speakers are measurably closer in behavior to native Maya than are immigrant Maya.

Cognitive Models of Folkecology

To determine whether group differences in behavior are reflected in distinct cognitive patterns, we elicited folkecological models from six men and six women in each group. In preliminary tasks, we asked informants "which kinds of plants and animals are most necessary for the forest to live?" (17). From these lists, we chose the 28 plants and 29 animals most frequently cited across informants. Scientific names were organized into categories used later in the analysis (Table 3). To ensure social diversity in each sample, no persons could have immediate kinship or marriage links.

To explore interactions among people and plants, we asked each informant to explain whether people in their community actually help or hurt each item on the plant list, and vice versa. We used principal components analysis to determine whether a single underlying model of ecological relations held for all informants in a population. Analysis was done on each of three 12 × 12 subject-by-subject matrices. Each matrix was adjusted for guessing. Consensus was assumed if (*i*) the first eigenvalue was notably larger than the second and accounted for most of the variance, and (*ii*) the first eigenvector was all positive. Under these conditions, the agreement pattern among informants should reflect a single common model, and first factor scores provide indices of the degree to which individuals' responses should reflect the consensus (18). For each group we found internal consensus: The first eigenvalue accounted for >50% of the variance and was three or more times the second eigenvalue. Finding consensus justified further study of group-wide patterns.

A Relation (Helps, Hurts) × Group (I, L, Q) ANOVA was computed on number of relations. Itzaj report more instances of humans affecting plants than Ladinos, and both groups report many more instances than Q'eqchi': $F(2, 33) = 157.37, P < 0.0001$. A Relation × Group interaction indicated a distinct pattern for each group: $F(2, 33) = 5.92, P < 0.01$. On average, Itzaj report helping over twice as many plants (18.7) as they hurt (7.1), Ladinos report helping (10.8) and hurting (10.2) equal numbers, and Q'eqchi' report hurting (3.4) over three times as many plants as they help (1.0).

To assess reported human impact, we computed each group's mean response to each plant (Table 4). Each "impact signature" ranges from entirely beneficial (+1), through neutral (0), to entirely harmful (−1). Itzaj report beneficial impact on all ecologically and economically important plants and absolute commitment to protect ramon and chicle (*Manilkara achras*).

Table 3. Peten plants and animals

Reference no.	Plant name	Reference no.	Animal name
	Fruit trees		Arboreal animals
P1*	*Brosimum alicastrum*	A1	bats (Chiroptera)
P2*	*Manilkara achras*	A2	*Ateles geoffroyi*
P3*	*Cordia dodecandra*	A3	*Allouatta pigra*
P4*	*Pimenta diocia*		*Allouatta palliata*
P5*	*Ficus obtusifolia*	A4	*Potus flavus*
	Ficus aurea	A5	*Nasua narica*
		A6	*Sciurius deppei*
	Palms		*Sciurius aureogaster*
P6*	*Sabal mauritiiformis*		
P7*	*Crysophilia staurocata*		Birds
P8*	*Orbignya cohune*	A7	*Penelope purpurascens*
	Scheelea lundelli	A8	*Crax rubra*
P9	*Chamaedorea elegans*	A9	*Meleagris ocellata*
	Chamaedurea erumpens	A10	*Tinamou major*
	Chamaedurea oblongata		*Crypturellus* spp.
P10	*Chamaedorea tepejilote*	A11	*Ramphastos sulfuratus*
P11	*Astrocaryum mexicanum*	A12	parrots (Psittacidae)
		A13	*Ara macao*
	Grasses/herbs	A14	*Ortalis vetula*
P12	herbs/underbrush	A15	*Columbidae*
P13	*Cyperaceae/Poaceae*		
			Rummagers
	Other plants	A16	*Tayassu tacaju*
P14*	*Swietania macrophylla*	A17	*Tayassu pecari*
P15*	*Cedrela mexicana*	A18	*Cuniculus paca*
P16*	*Ceiba pentandra*	A19	*Dasyprocta punctata*
P17*	*Gliricidia sepium*	A20	*Mazama americana*
P18*	*Caesalpinia velutina*	A21	*Odocoileus virginianus*
P19*	*Lonchocarpus castilloi*	A22	*Tapirus bairdii*
P20*	*Piscidia piscipula*	A23	*Dasypus novemcintus*
P21*	*Calophyllium brasilense*		
P22*	*Pseudobombax ellipticum*		Predators
	Bernoullia flammea	A24	*Felis onca*
P23*	*Vitex gaumeri*	A25	*Felis wiedii*
P24*	*Senna racemosa*	A26	*Felis concolor*
P25*	*Bucida buceras*	A27	*Boa constrictor*
P26*	*Vitis tiliifolia*	A28	*Bothrops asper*
P27	*Cnestidium rufescens*	A29	*Herpetotheres cachinnans*
P28	various epiphytes		

*Species counted in tree-frequency study (=44%, 50%, 54% of trees in Itzaj, Ladino, Q'eqchi' parcels, respectively).

Table 4. Human impact and ecological centrality rankings

Plant	Common name	Itzaj		Ladino		Q'eqchi'	
		Impact	Centrality	Impact	Centrality	Impact	Centrality
P1	Ramon	1.00	0.64	0.33	0.64	0.00	0.21
P2	Chicle	1.00	0.62	0.42	0.61	−0.58	0.13
P15	Cedar	0.83	0.11	0.17	0.14	−0.67	0.12
P14	Ciricote	0.83	0.11	0.08	0.30	−0.75	0.09
P3	Mahogany	0.83	0.48	0.50	0.47	0.00	0.04
P9	Xate	0.75	0.20	0.58	0.10	−0.25	0.03
P4	Ceiba	0.67	0.36	0.55	0.16	0.00	0.00
P16	Guano	0.67	0.05	0.75	0.20	−0.25	0.05
P6	Madrial	0.67	0.40	0.17	0.36	0.33	0.04
P17	Allspice	0.67	0.09	0.33	0.12	0.00	0.07
P22	Amapola	0.58	0.25	0.00	0.29	0.00	0.17
P2	Chapay	0.58	0.30	−0.33	0.09	0.00	0.08
P11	Corozo	0.58	0.13	−0.50	0.20	0.00	0.00
P8	Broom palm	0.58	0.09	0.00	0.22	0.25	0.09
P10	Pacaya	0.58	0.20	0.58	0.15	0.00	0.02
P13	Grasses	0.50	0.34	0.17	0.25	0.08	0.07
P18	Chaltekok	0.42	0.07	−0.14	0.01	−0.08	0.00
P20	Jabin	0.42	0.17	−0.44	0.13	0.00	0.01
P19	Manchich	0.42	0.06	−0.60	0.00	−0.25	0.01
P21	Santamaria	0.25	0.16	−0.18	0.11	0.00	0.02
P12	Herbs	0.17	0.37	−0.25	0.25	0.00	0.05
P5	Strangler fig	0.08	0.47	−0.67	0.60	−0.08	0.15
P23	Yaxnik	0.08	0.28	0.00	0.00	0.00	0.01
P25	Pukte	−0.25	0.16	−0.13	0.14	0.00	0.01
P27	Water vine	−0.33	0.01	−0.25	0.06	0.00	0.02
P26	Cordage vine	−0.33	0.07	0.00	0.17	−0.08	0.03
P24	Kanlol	−0.58	0.03	−0.75	0.06	0.00	0.00
P28	Killer vines	−0.58	0.09	−0.67	0.24	−0.08	0.01

Itzaj call ramon "the milpa of the animals" because many bird and mammal species feed on its fruits and leaves. The chicle tree also is visited often by animals and, as with ramon, has a long history of local use. Extraction of chicle resin for chewing gum has been Peten's prime cash source in this century. Itzaj report variable impact on herbaceous undergrowth, strangler figs (*Ficus* spp., which nourish many animals but kill other trees), and yaxnik (*Vitex gaumeri*), which Itzaj qualify as a marginally useful "forest weed." Itzaj report harmful impact on pukte (*Bucida buceras*), another forest weed, on kanlol (*Senna racemosa*), a "village weed," and on vines cut for water and cordage. Ladinos also report positive impact for valuable plants (including *Ceiba pentandra*, Guatemala's national tree) but variable impact on most plants. Q'eqchi' report positive impact only for thatch palms and negative impact on Peten's most important cash sources: chicle, tropical cedar (*Cedrela mexicana*), mahogany (*Swietania macrophylla*), and xate (decorative *Chamaedorea* dwarf palms collected for export). Overall, Q'eqchi' see little impact on plants, a striking observation given that this group has the most destructive agroforestry and mentions uses for nearly all plants.

Regression analysis reveals that, for Itzaj, weed status and ratings of human impact predict (normalized) frequencies of trees observed in informant parcels: $r^2 = 0.46$; $F(2, 20) = 7.58$, $P = 0.004$; both predictors, $P \leq 0.01$. No comparable relation emerges for Ladinos or Q'eqchi'. Ramon exemplifies this tendency. Apart from the weed trees and leguminous hardwoods, *Piscidia piscipula* and *Lonchocarpus castilloi*, which are equally dominant for Itzaj and Ladinos, ramon is most common to Itzaj parcels (2.6× more numerous than for Ladinos, 4.2 more than for Q'eqchi').

To explore folkecological relationships between plants and animals, we asked informants to explain how each plant helped or hurt each animal and how each animal helped or hurt each plant. We examined residual agreement to find differences among groups sharing overall consensus. Agreement predicted by the model (indexed by the product of informants' consensus scores) was subtracted from observed agreement (adjusted for guessing), yielding residual agreement (19). If there is only a single model fitting all individuals, there should be only chance residual agreement.

Using agreement adjusted for guessing as the dependent variable, a cross-group consensus emerged: ratio of eigenvalue 1:2 = 12.3, variance = 67%. Most interactions involve plants helping animals by providing food or shelter. On average, Q'eqchi' recognize far fewer relations (46.8) than Ladinos (163.2) or Itzaj (187.5) who do not differ from each other: $F(2, 33) = 23.10$, $p < 0.001$, Scheffe Ps < 0.05. We analyzed the residual agreement matrices: Each group's 12×36 matrix consisted of the means of each individual's residual agreement with all other group members and with all members of each of the other two groups. There was reliable within-group agreement: for each group, $F(2, 22) > 23$, $P < 0.001$. Itzaj and Q'eqchi' have greater within- than between-group residual agreement: For all pairwise comparisons, $t(11) > 6.0$, $P < 0.0001$. Ladinos show higher within- than between-group residual agreement vis-a-vis Q'eqchi' but do not share more residual agreement with one another than with Itzaj. Itzaj and Ladinos show a large overlap for which plants help which animals (86% of relations where half or more Ladinos agreed were cited by >25% of the Itzaj). Ladinos differ from Itzaj by generalizing beneficial effects on animals of economically and culturally important plants, such as mahogany and ceiba, without apparent justification. Overall, Ladino and Itzaj models converge on how plants help animals, and the Q'eqchi' model is a limited subset (Fig. 2).

Reports of how animals affect plants also yielded large differences. Q'eqchi' acknowledge few such interactions and were not included in consensus analysis (of 812 possible animal-plant pairings for each of 12 participants, only 13 interactions were recognized). For Itzaj and Ladinos, there is strong cross-group consensus (ratio eigenvalue 1:2 = 18.9, variance = 72%) but also greater residual agreement within than between groups: $t(11) > 4.5$, $p < 0.0001$. Negative interactions (animals hurting plants) occur with equal frequency (8.0% of cases by Itzaj, 8.2% by

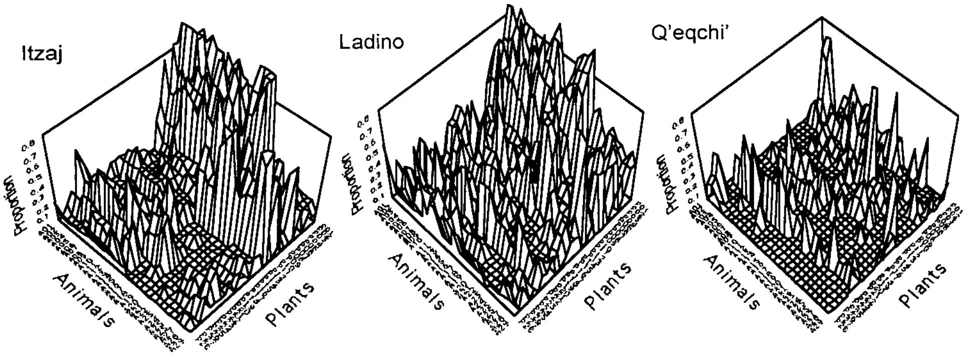

FIG. 2. Reported positive plant impact on animals for Itzaj, Ladinos, and Q'eqchi'. Plant and animal numbers refer to the ordering of species listed in Table 3. The height of each point reflects the proportion of informants reporting each interaction.

Ladinos). But Itzaj are 4× more likely to report positive interactions ($F(2, 33) = 3.74, p < 0.05$) and 3.4× more likely to report reciprocal relations (a plant and animal helping each other) ($t(22) = 3.31, p < 0.005$).

Itzaj also have more differentiated views of animal-plant relationships. To illustrate, plant kinds were collapsed into four categories (Fruit Tree, Grass/Herb, Palm, Other), as were animal categories (Arboreal, Bird, Rummager, and Predator) (Table 3). An ANOVA reveals a Plant × Animal interaction for Itzaj ($F(9, 99) = 26.04, P < 0.0001$) but not Ladinos. Ladinos report that all animal groups (save predators) interact with all plant groups in roughly the same ways. On a qualitative level, Ladinos infer that animals most harm plants by eating fruit. Itzaj have a subtler view, based on properties of the seed and how the animal chews and digests: If the seed is soft and the animal crunches the fruit casing, the interaction is harmful because the animal is likely to destroy the seed; if the seed is hard and digestion is rapid, the interaction is likely to be helpful if the seed passes through the animal's body, as the animal assists seed dispersal and fertilization.

Regression analysis reveals that, for Itzaj, ecological centrality (number of plant-animal associations in a group's aggregate model for each plant) and combined utility (aggregated number of uses attributed to each plant for wood, shelter and cash combined) predict impact signature, that is, which plants Itzaj seek to protect: $r^2 = 0.44$; $F(2, 25) = 9.13, P < 0.001$; both predictors <0.01. For Ladinos, only cash value reliably predicts impact: $r^2 = 0.34, F(2, 25) = 6.55, P < 0.01$. This indicates that Ladinos protect plants having cash value. For Q'eqchi', none of the variables predict impact, and the (nonsignificant) correlations are consistently negative, indicating the Q'eqchi' tend to destroy valuable plants. Comparing peaks in Fig. 2 with Table 4 rankings shows that only Itzaj see people as generally benefiting plants that benefit animals (e.g., ramon and chicle consistently have the highest positive impact on animals as well as the highest human impact signatures).

To further distinguish the role of humans in Itzaj and Ladino folkecology, we did a follow-up study with new informants of interactions among listed animals and people. Both groups share consensus on negative animal–human interactions (ratio eigenvalue 1:2 = 3.3, variance = 45%), based mainly on animal damage to milpa crops. But Itzaj report more positive animal–human interactions, based on use of animals and their role in forest regeneration: $F(1, 112) = 98.38, P < 0.001$. This is the pattern seen in the animal–plant interaction study. Correlations ($P < 0.05$) between how animals help plants and how humans help animals are positive for Itzaj ($r = 0.40$), negative for Ladinos ($r = -0.50$).

In sum, results indicate overlapping but distinct models for each group. These distinctions represent interactions, not general differences in response thresholds: Ladinos respond at the same rate as Itzaj for plant–animal, negative animal—plant, and negative animal–human relations but report dramatically fewer positive animal–plant, plant—human, and animal–human relations; Q'eqchi' also show an interaction. Overall, Ladino models are measurably closer than Q'eqchi' models to Itzaj models. Ladino folkecology differs from Itzaj folkecology by its lack of consideration for reciprocal relations between humans, plants, and animals and is less intimately related to behavior.

Social Networks and Learning Forest Expertise

To examine how ecological models and practices are learned, we used social network analysis (20). We used the twelve informants from the plant–animal study, asking each to name, in order of priority, seven persons outside the household "most important to your life" and to justify inclusion of these names in the informant's social network. We also asked each to name by priority seven sources "you would turn to if you do not understand something about the forest" and to justify inclusion of names in the informant's expert network. Using a "snowball" method, we then elicited social and expert networks from the first and last persons named in each original informant's social network.

In their social networks, Itzaj name nobody outside their ethnic community, Q'eqchi' name 1 Ladino, Ladinos name 1 Itzaj. Overall social network density (Dh = ratio of possible to actual names) is substantially greater for Q'eqchi' ($Dh = 4.6$) than Ladinos ($Dh = 2.4$) or Itzaj ($Dh = 1.9$), as is degree of interconnectedness [i.e., λ-level = minimum number of ties that must be severed for at least one person to be disconnected from the group: $\lambda(Q) = 4$, $\lambda(L) = 2$, $\lambda(I) = 1$]. By contrast, overlap between social and expert networks is greatest for Itzaj and least for Q'eqchi'. For Itzaj, 14 well cited (chosen three or more times) social partners are among the 22 well cited forest experts. For Q'eqchi', only 6 well cited social partners are among the 18 well cited experts. For Ladinos, 11 well cited social partners are among the 25 well cited experts (all male), and the 3 top Ladino experts are also among the 6 most socially interconnected Ladinos ($\lambda = 5$). The top 10 Ladinos name Itzaj as their expert 6:1.

For Itzaj, diffusely interconnected social and expert networks suggest multiple social pathways to assimilate and store information. One possibility consistent with this structure is that individuals gain information about the forest in distinct ways. Another possibility is that ecological knowledge is directly socially transmitted in similar ways for different individuals. To test the latter possibility, we analyzed patterns of residual agreement in relation to social and expert network structure. We focused on nonempty plant–animal cells (counting any cell as nonempty if recognized as such by our most cited expert Itzaj informant) because knowledge transmission should primarily take the form of noting an existing relationship. Residual agreement among informants was uncorrelated across tasks ($0.02 < r^2 < 0.15$ between positive plant–animal, positive animal–plant, negative animal–plant). No reliable correspondence emerged between patterns of residual agreement and similarity in social or expert networks (socially linked individuals don't agree with each other more). Itzaj culture may well sensitize members to relevant variables in a dispersed and generalized way, but individual knowledge of specific plant–animal interactions proceeds in significant part through independent discovery rather than direct social transmission. Indeed, Itzaj acknowledge consulting experts on difficult problems but mostly claim to acquire knowledge by "walking alone" in the forest they call "the Maya House."

For Ladinos, overlap between socially connected individuals and Ladino experts (who name Itzaj as experts) suggests reliable but informal networks for learning about the forest from Itzaj. To test this, we regressed gender and frequency of being cited as an expert against Ladino consensus scores in the combined Itzaj-Ladino consensus model on the plant–animal task (less one informant unavailable for network analysis). The r^2 on Ladino scores was 0.63 ($F(2, 10) = 6.97, P = 0.02$) with gender ($P = 0.02$) and expertise ($P = 0.008$) reliable. One subgroup (4 men, 1 woman) averaged 5.8 expert citations, 6.0 social network citations, and a first-factor consensus of 0.73 (vs. 0.75 for Itzaj). Averages for the other subgroup (5 women, 1 man) were, respectively, 0, 1.3, and 0.59. Male Ladino experts appear to be driving the Ladino population to a convergence of knowledge with Itzaj.

For Q'eqchi', a densely connected social structure favors communal and ceremonial institutions that organize accountability. Only Q'eqchi' practice agroforestry in corporate groups: Neighbors and kin clear and burn each household's plot, kin groups seed together, and the community sanctions unwarranted access to family stands of copal trees (*Protium copal*), whose resin is ritually burned to ensure the harvest. But this social network is radically dissociated from forest expertise (experts most cited by Q'eqchi' are a Washington-based non-governmental organization and the government organization responsible for management of the Maya Biosphere). In the absence of socially assimilable and ecologically relevant information, this implies that institutional monitoring of access to resources, cooperating kin, commensal obligations, a vibrant indigenous language, and familiarity with the land and its species do not suffice to maintain the community's common-pool resources.

In brief, two sets of factors militate against Q'eqchi' preservation of Lowland ecology: (*i*) linguistic isolation coupled with a compact social structure that forecloses intercultural exchanges apt to convey appropriate Lowland techniques; and (*ii*) selective use of inappropriate Highland techniques (clear-cutting, cash-cropping, continuous cultivation) coupled with failure or inability to transfer Highland techniques favoring forest maintenance (intercropping, terracing) (21). Moreover, Q'eqchi' immigrants tend to invoke corporate and ceremonial ties with the sacred Highland mountain valleys when faced with economic and ecological problems (e.g., banana blight). This may function to detour access to ecological information relevant to Lowland commons survival (22).

Conclusion

Theories of rational action predict that increases in the number of noncooperative players in the environment and their apparent disregard for the future should lead even native cooperators to abandon long-term interest in sustainability for short-term use (23), unless institutional restraints compel individual action toward the common good (24). Our results show that different cultural groups subject to equal pressures on their common resources respond with strikingly different patterned behaviors and cognitions. The Itzaj community is the most socially atomized but the one whose individuals most clearly learn to act to maintain the common environment. The Q'eqchi' community is the most socially interconnected and ceremoniously institutionalized but is least likely to preserve the resource base. No doubt, maximization of short-term self-interest and institutional constraints are important factors in determining and describing actions on common-pool resources, but there is also an important cognitive dimension to how people learn to manage common property resources.

It is no surprise that native Maya with centuries-old dependence on a particular environment manage to better resist actions that lead to its degradation than immigrants, although the underlying models for behavior and modes of learning are not predictable on *a priori* grounds. What is surprising is that Ladino immigrants who share no evident tradition with native Maya come to measurably resemble native Maya in thought and action. Network analyses reveal reliable but noninstitutionalized channels that allow socially well connected Ladinos access to Itzaj expertise.

This bears on the seemingly intractable problem of "upscaling" lessons of local commons to increasingly mobile and multicultural societies: Even in a relatively open-access system, if there is ready access to relevant information, then ecologically sound behaviors may be learned by relative newcomers who have no institutional compulsion, cognitive predisposition, or cultural tradition favoring commons survival. Having the time to learn, however, poses a daunting problem. Rates of cultural and environmental degradation in neotropical areas are awesome by any standard because of global economic and political processes that function similarly across such areas.

Earlier research on Itzaj focused primarily on maize production (25) to better understand the cereal basis for ancient Maya civilization (26). But there is increasing argument that tree tending and multicropping were important to Pre-Columbian Maya civilization (27) and perhaps critical to the survival of Lowland Maya over two millennia of intermittent and catastrophic upheaval (28). Our studies provide data and findings to develop this line of research. They also raise the possibility that a better understanding of intricate cultural patterns favoring environmental maintenance may enhance their value and reduce their chances for extinction in the next millennium.

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