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ORIGINAL ARTICLE

The Construction of Cultural Consensus Models to Characterize Ethnogeological Knowledge

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Abstract

Limited research interest has been focused on the understanding of culturally framed geology knowledge in comparison with more mature ethnosciences such as ethnobotany or ethnogeography. Ethnogeology is the scientific study of human relationships with and knowledge of the Earth system, generally investigated within the context of a specific culture, through the implementation of field geologic and field ethnographic methods. The purpose of this paper is to present the use of cultural consensus analysis for the exploration of culturally framed knowledge of geological processes. We used rapid assessment methods from the discipline of field ethnography with local cultural consultants, to construct a cultural consensus questionnaire about karst processes and riverine geomorphology in Puerto Rico (PR) and the Dominican Republic (DR). We employed the results from structured interviews and identified common themes that we organized as a cultural consensus model (CCM). Our results indicate a CCM for the knowledge domain of karst processes and riverine geomorphology that is shared by inhabitants of karst regions in DR and PR, which constitutes a reliable system of local ethnogeologic knowledge. Conceptual key elements of the model include use of metaphors and analogies to describe geomorphic processes and speleothem. We discuss the use of rapid assessment and cultural consensus analysis as a method for ethnogeological research, and the implications for place-based geoscience education, participatory research, and geoheritage.

Keywords Ethnogeology · Caribbean culture · Caribbean karst · Caribbean ethnography

Introduction

Indigenous or historically resident (e.g., Hispanic or Latinx) communities may perceive their natural surroundings differently from outside observers trained in the "Western" or Euro-American tradition. This phenomenon derives from characteristics that are unique to these communities, such as pre-colonization historical continuity, language (intact or fragmented), distinct lifeways and belief systems, or culturally defined connections to the land. Traditional ecological knowledge (TEK, alternatively referred to as indigenous knowledge) exceeds the epistemological boundaries of non-indigenous ideas of physical characteristics of the world (Cajete 1999). This way of perceiving and approaching the natural world embraces and highlights unique artistic, spiritual, intuitive, and cognitive ways (McLeod 2000; Kovach 2010; Wulff 2010).

Ethnosciences are focused on the ways that individuals and communities obtain and organize knowledge of specific subjects, from physical objects to concepts. One of the earliest examples of the use of the *ethno-* prefix in science is the work of ethnographer and linguist John P. Harrington (1916), who collected the ethnogeographic knowledge of the Tewa people of New Mexico and also co-authored a volume on the *Ethnobotany of the Tewa* (Robbins et al. 1916). Ethnobotany has subsequently come to be recognized as a mature discipline with a considerable literature base (e.g., Harrington 1916; Girón et al. 1991; Homma 1992; Schultes and Reis 1995) and ethnogeologists aspire to the same. Ethnogeology (Kamen-Kaye 1975; Murray 1997; Semken 2005; Londoño et al. 2016) is defined as the scientific study

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of people's knowledge of and relationships with Earth systems (i.e., with Earth materials, structures, processes, hazards, resources, and other phenomena). Ethnogeologic research combines methods of ethnography and geology, is primarily field-based, and is typically carried out in the context of a particular cultural or geographically situated group (e.g., Londoño et al. 2016). Ethnogeologic methods have also been applied in mainstream communities to identify community-based knowledge relevant to improved management of soil and water resources (WinklerPrins and Barrera-Bassols 2004; Gartin et al. 2010). Oral histories and other sources of traditional knowledge are also included as reliable sources of information on relationships that people have with their surrounding landscape (Basso 1996; Morton and Gawboy 2000; Gibson and Puniwai 2006; Chinn et al. 2014), yielding a holistic description of the study area (Kelley and Francis 1994; Cajete 1994). Ethnogeologic research offers unique observations and analyses of Earth systems that contribute to the greater body of geoscientific knowledge (Murray 1997), support resilience and sustainability of local environments and communities (Capra et al. 2015), and have the potential to inform place-based and culturally inclusive methods of geoscience teaching (Semken 2005; Palmer et al. 2009; Johnson et al. 2014; Reano and Ridgway 2015; Semken et al. 2017).

The study described in this paper was directed at uncovering and characterizing ethnogeological knowledge, through field ethnographic work with local cultural informants (participants) and application of cultural consensus theory to analyze the field data and generate a coherent, reliable consensus-based model for ethnogeology of two geologically and culturally significant regions of Puerto Rico (PR) and the Dominican Republic (DR). It was initially motivated by the first author's familial and cultural ties to these countries and his deep familiarity with long unmet regional issues and needs that could be served by this type of research.

Background

Caribbean Inhabitants and Their Relationship with Karst

Indigenous families residing throughout the northern Caribbean archipelago for many centuries have accrued rich empirical knowledge about Earth processes and environments that have been transferred from generation to generation. In modern Caribbean countries, such as the DR and PR where our study is situated, the present-day descendants of pre-Columbian *Taíno* (Indigenous Caribbean; also known as Island Arawak: Brinton 1871) dwellers still identify as being of that culture, still reside in what they consider to be traditional homelands, and still use elements of pre-conquest TEK in combination with practices of post-colonial African and European inhabitants.

In this study, we worked specifically with inhabitants of the northern karst belt (also known as the karst belt) in Puerto Rico (often known as *Jíbaros*[1]) and with *campesinos*[2] from the Dominican Republic karst region, located at the east end of the island of Hispaniola. Both karst regions are characterized by caves, sinkholes, high relief, and abundant connectivity between groundwater and surface water systems. Karst is a geological feature that has influenced cultural norms and resource use in many parts of the Caribbean (Day 2010). The karst regions hold great cultural significance for many Puerto Ricans and Dominicans (as discussed below), directly influence quality and sustainability of water and land resources in these two countries (e.g., Lugo et al. 2004; Padilla et al. 2011), and also have the potential for geoheritage, as has been recognized throughout the Caribbean (Christian 2018).

Recent evidence from carbon-14 isotopic dating (Rodríguez-Ramos 2017) has dated cave art (pictography and pyrography) in the Las Cabachuelas caves of Morovis, PR, at 400 CE, suggesting human presence and activities in Caribbean caves has extended for more than a millennium. Caribbean indigenous groups, especially *Taínos*, occupied different parts of the Greater Antilles from Cuba to Puerto Rico, including the Bahamas and Jamaica (Rouse 1989, 1992). *Taíno* mythology incorporates elements of karst as a central theme within creation stories (Pané 1999). The countries of DR and PR share a close ethnohistoric evolution (Bukhari et al. 2017) as well as cultural norms, and both have very similar geology. This historical relationship includes similar use of karst features and landscapes as important locations for ceremonies, and common appearance of karst as a theme for place names, family oral tradition, and artistic expressions (Alvarez Nazario 1972; Dominguez-Cristobal 1989, 1992, 2007; Pané 1999).

But as of yet, ethnogeological knowledge of any type has been scarcely used in DR or PR to inform either formal teaching of natural or environmental sciences in schools and colleges, or informal educational outreach (also known as interpretation: Tilden 1957) offered to the public at parks and preserves such as El Yunque National Forest in PR. There is unmet potential to render both of these modalities more place-based and culturally informed.

Geographic and Geologic Setting

More than 50% of the Caribbean region (about 130,000 km^2; Day 1993) is karst terrain formed on carbonate rocks with

[1] Coming from the indigenous *Taíno* word referring to a person of the forest.
[2] *Campesino* is the Spanish word for farmer. It is widely used in the Caribbean, especially in the Dominican Republic to substitute *jíbaro* (PR) or *guajíro* (Cuba).

ages ranging from Holocene to Jurassic (0 to 200 Ma; Troester et al. 1987). As shown in Fig. 1, the islands of the Greater Antilles (including DR and PR; adjacent and separated by 145 km) have expansive areas of karst terrain. The Puerto Rican karst terrain formed in a tropical climate and covers more than a quarter of the main island (Lugo et al. 2004). The northern karst belt (locally known as *karso norteño*) formed by karstification of exposed Oligocene and Miocene limestones (Miller and Lugo 2009; Monroe 1976), whereas the Dominican karst, occupying about 52% of the land surface of DR, formed on Pliocene and Pleistocene limestones (Gunn 2004).

Data Collection

Rapid Assessment

To collect ethnogeological knowledge within several cultural domains relating to karst features and geomorphologic processes, we used three rapid-assessment field ethnographic methods (Bernard 2011): free listing, grand tour unstructured questions, and participant observation. Rapid assessment, used increasingly in applied field anthropology (Cove and Pelto 1993; Laban Moogi Gwako 1997; Chambers 2006; Alemi et al. 2017), is the application of the same methods used in conventional long-term field ethnography over a shorter interval, when the development of long-term rapport with participants is not necessary to obtain useful data (Harris et al. 1997; Beebe 2001; Handwerker 2001; Bernard 2011). The total time invested in this study, including networking with participants, all fieldwork, and analysis was approximately 3 years, which classifies it as rapid assessment compared to conventional studies with 10 years of fieldwork or more.

Fieldwork was conducted during the winter of 2014 and the summer months of 2016 within the karst regions of DR and PR. In the DR, most fieldwork was carried out in the east (around the Altagracia and Seibo provinces), whereas in PR fieldwork was done in a broader area within the northern karst belt, covering several municipalities (see Fig. 2).

Participants, Recruitment, and Procedures

This study encompassed cultural consultation with 80 volunteer participants (i.e., cultural informants) in total: 40 in DR and 40 in PR. The protocol used to locate and work with all participants in this study was in compliance with the Institutional Review Board at our university (study number 00000965). All participants recruited were inhabitants of the karst regions as delineated on maps (Fig. 2), typically agriculturists and self-identified *jíbaros* or *campesinos*, and all were 18 years of age or older. Demographic information including age, gender, time residing in the area, and occupation was collected at the end of the interaction with each participant. Personally identifying information for all participants was kept confidential, and all of our results are reported here in the aggregate. All verbal and written communication with

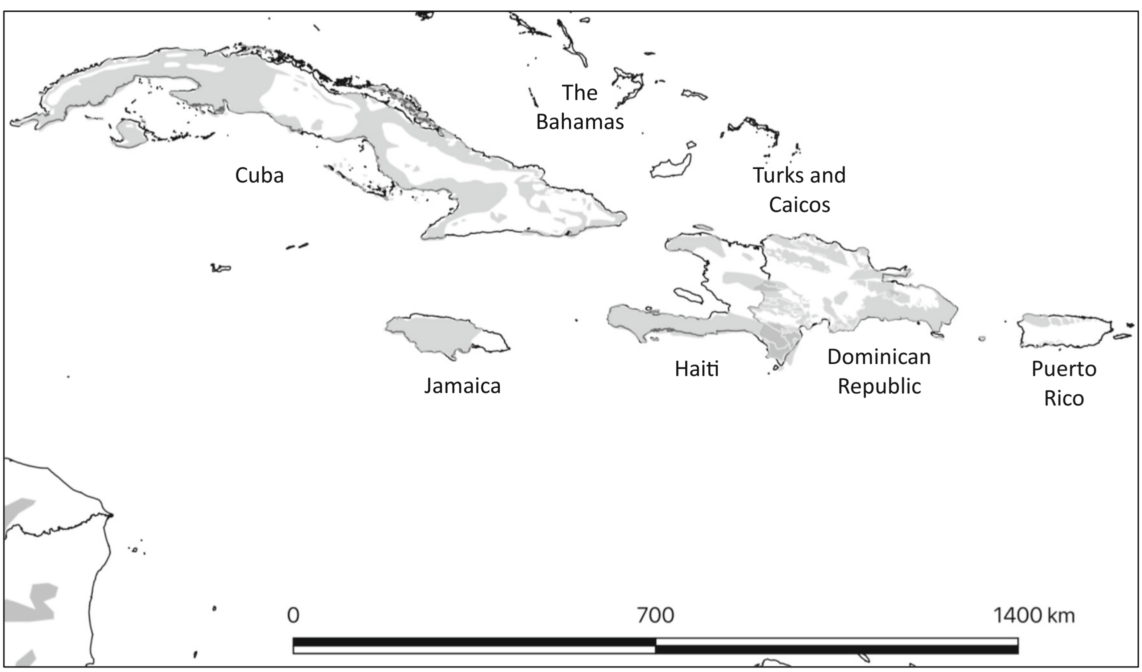

Fig. 1 Karstic terrain within the Greater Antilles. Gray-colored areas represent carbonate rocks in where karstic characteristics are observable *at the surface geology*. QGIS Development Team (2019). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

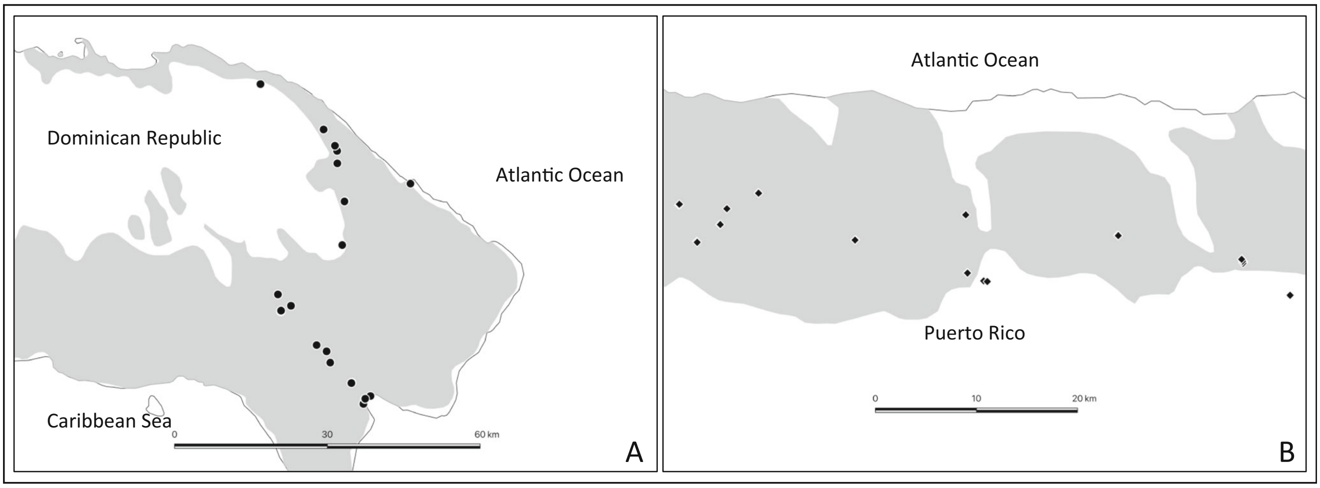

Fig. 2 Research setting area and fieldwork locations. Gray-colored regions are representing karstic surface geology. QGIS software was used to create this figure

participants was in Spanish, in which all participants were fluent.

Participants were recruited using the method of snowball sampling, also known as chain-referral (Goodman 1961; Bernard 2011), a nonprobability sampling method, in which each participant is asked to recommend additional participants from among those they deem similarly proficient in the knowledge domain. We used this sampling method in order to identify a statistically sufficient number of participants from within the large and (to us) mostly unfamiliar populations of inhabitants of the DR and PR karst regions. We sought to minimize potential biases associated with chain-referral (Heckathorn 1997) by initiating our sampling through our local field assistant, a key informant (Deaux and Callaghan 1985) with demonstrated expertise. We asked each subsequent participant to offer a list of other possible candidates to participate in the study and selected new participants from each list provided by participants. Candidates recommended through chain-referral who were not inhabitants of the karst regions were not included in this study.

Free Listing

Free listing was carried out in the preliminary stages of the study to focus subsequent fieldwork by identifying the most salient cultural domains of knowledge related to karst features and geomorphic processes in the two study regions of DR and PR. To prompt free listing by our study participants, we chose five initial domains of knowledge on which to question them: uses of local rocks (particularly limestones), textures of local rocks, karst hydrology (drainage and circulation), uses of caves, and the surrounding geography. We selected these domains on the basis of our own prior knowledge of and prior published work (cited above) on geology and geography of the study regions. It was understood that these domains were only prompts and that in their responses, our participants would likely redefine them. The complete list of questions we developed to prompt free listing is presented in Appendix Table 3, in Spanish and translated into English. Example questions included the following: What are the traditional uses of rocks? What are the locations that you think you will be able to find water? What are the traditional uses of caves? We asked each participant to construct a list in response to these questions and hence identify as many items they could within each of the five domains of knowledge. Informants who were more knowledgeable within a given domain of knowledge typically provided longer lists than other participants. Lists generated by participants were analyzed for rank and word-position using the software package UCINET (Borgatti et al. 2002). Following each of the free listing interviews with participants, we asked them to offer interpretive walks in the surroundings while responding to grand tour questions, described below, in order to elaborate on themes identified by the researcher during the interviews.

Grand Tour Questions

Grand tour questions are those that ask a participant to provide a more unbounded "tour" of a topic they know well (Spradley 1979), drawing on "the power of language to construe setting" (Frake 1964, cited in Spradley 2003, p. 49). They are used to provoke in the participant more detailed descriptions of particular cultural scenarios and interpretations. Grand tour questioning improves the researcher's interpretations in the field, and minimizes the researcher's own culturally informed inputs in documenting the observations (Spradley 1979, 2003). Responses to grand tour questions also have the potential to lead into other culturally relevant inquiries. The method of grand tour questioning was employed early in the fieldwork phase after free listing, and subsequently after the construction of the cultural consensus questionnaire discussed below. Grand tour questions were used to provoke a more descriptive interpretation of karst features, particularly caves, and participant responses included metaphors, stories, and specific examples of events. We commonly asked participants to give an actual grand tour, in the form of interpretative walks inside and surrounding caves. We often found that a single grand tour question could keep a participant talking for more than an hour.

Participant Observation

Participant observation is a method that is primarily qualitative, but thematic or numerical analysis of transcribed observations can yield quantitative as well as qualitative data (Bernard 2011; Williams and Semken 2011; LeCompte and Schensul 2012). We carried out participant observation over the entire duration of the ethnographic fieldwork phase to triangulate free listing and grand-tour questioning. Observation of participant behavior in the field enabled us to gauge participant rapport toward the researcher and to capture additional data outside of the grand tour framework, including local cultural interpretation in the form of place-names, analogies, stories, pictures, and metaphors. Participant observations were collected in the form of audio recordings, written notes, and pictures during interactions with researchers. Data collected from participant observation were used to inform the researchers in the construction of the cultural consensus questionnaire. In this study, participant observation allowed us to watch for potential effects of participants' awareness of being observed (referred to as reactivity). In many cases, we observed that participant reactivity during the interview decreased as rapport was built, increasing our confidence in the knowledge that was shared. This allowed us to accrue data that we consider to be more reliable than what could be obtained in more structured settings such as indoor focus groups. Further, our notes from participant observation helped us improve our own understanding of local ethnogeological interpretation.

What Constitutes Reliable Ethnogeologic Knowledge? Application of Cultural Consensus Theory

We applied cultural consensus modeling to generate a reliable (trustworthy) consensus-based model of ethnogeologic knowledge from the diverse data streams obtained from the field ethnographic studies described above. Cultural consensus theory was developed in the mid-1980s by Romney et al. (1986) as a means to representatively characterize cognitive patterns about a given system of knowledge in a group, while also capturing the full diversity of expression among the different group members. This is done through analysis of patterns of an agreement to assess: (1) different levels of expertise among individuals, (2) the degree to which there are individuals who agree on a single cultural model, and (3) the degree to which there is disagreement among subgroups (Romney et al. 1986; Hruschka et al. 2008). The analysis to find cultural consensus enables the researcher to determine how much of a total specific domain of knowledge is shared among the consultants; this is reported as a competence score: the probability that an informant knows the correct answers, based on consensus among other consultants. An important aspect of cultural consensus theory is that it determines the locally accepted cultural model (also known as a cultural consensus model or CCM) by examining a respondent's answers, rather than relying upon the researcher's prior assumptions. Thus, it can yield models that are unique to each cultural setting and to the specific domain of knowledge being investigated (Romney et al. 1987).

To generate a CCM for ethnogeological knowledge in the karst regions of DR and PR it was first necessary to construct a standardized cultural consensus questionnaire, administered to all participants, with items representing the full range of ethnographic data obtained from a free listing, grand-tour questioning, and participant observation. The questionnaire was administered to each consultant in the form of a structured interview. To avoid exhausting the participants, we chose to limit interviews to no more than 60 min each. We constructed a cultural consensus questionnaire (Appendix Table 4, in Spanish and English) containing 73 items, a number sufficiently large to overcome sampling errors and to reject an assumption of equal competence among participants (Hruschka and Maupin 2013). Items focused on analogies, metaphors, and similes to describe karst processes and riverine geomorphology. Items were written so that participants could simply indicate whether they considered each of the findings from the prior fieldwork to be true or false in their option. Several items probed participants' agreement with attribution of anthropomorphic qualities to landscape features and processes (e.g., caves are alive). Responses were coded using 1 for "true" or "I agree," and 0 for "false," or "I do not agree."

Results

General Sample Characteristics

A total of 80 participants were recruited in this study. Table 1 provides descriptive statistics of the overall sample and the sample subdivided by gender and country. A total of 30 participants (37.5% of the study population) were women. Participants ranged in age from 19 to 98 years, with a mean of 56.8 ± 17 years. In both DR and PR, females on average resided longer in the karst regions than did males (Table 2).

Table 1 Descriptive statistics of cultural consensus analysis

Variable	Number of respondents Total (N = 80)	Females ($n = 30$)	Males ($n = 50$)	Statistic	P	1st ratio*	2nd ratio*
Dominican Republic and Puerto Rico							
Mean Age (SD) [Years]	56.18 (17)	57.6 (17.51)	55.32 (16.81)	$t = 0.01$	0.49		
Mean years residing at the location of the interview (SD) [Years]	46.25 (21.67)	45.5 (25.22)	46.71 (19.45)	$t = 0.43$	0.33		
Cultural Consensus Analysis						29.33	5.94
Cultural consensus competence§	0.58 (0.21)	0.61 (0.19)	0.56 (0.22)	$t = -2.5$	< 0.05		
Cultural consensus agreement	0.36 (0.12)	0.41 (0.11)	0.34 (0.12)	$t = -5.6$	< 0.05		
Dominican Republic	($N = 40$)	($n = 9$)	($n = 31$)				
Mean age (SD) [years]	54.92 (19.22)	65.44 (21.92)	52.61 (17.72)	$t = 1.19$	0.13		
Mean years residing at the location of the interview (SD) [years]	46.87 (22.09)	54.89 (29.43)	44.47 (19.36)	$t = 0.61$	0.28		
Cultural Consensus Analysis						13.55	2.94†
Cultural consensus competence	0.53 (0.21)	0.57 (0.20)	0.51 (0.22)	$t = -0.75$	0.23		
Cultural consensus agreement	0.30 (0.09)	0.32 (0.09)	0.30 (0.10)	$t = 0.65$	0.27		
Puerto Rico	($N = 40$)	($n = 21$)	($n = 19$)				
Mean Age (SD) [Years]	56.85 (14.66)	65.44 (21.92)	52.61 (17.72)	$t = -0.98$	0.17		
Mean years residing at the location of the interview (SD) [years]	46.65 (21.52)	50.26 (19.59)	41.48 (22.78)	$t = 1.3$	0.1		
Cultural Consensus Analysis						17.22	3.66
Cultural consensus competence	0.63 (0.19)	0.62 (0.19)	0.63 (0.20)	$t = 0.97$	0.17		
Cultural consensus agreement	0.41 (0.11)	0.41 (0.11)	0.41 (0.10)	$t = 0.94$	0.18		

* First and second eigenvalues ratios are reported as evidence to claim that the cultural consensus model is satisfied

§ One negative competence is reported among participants in the Dominican Republic. The table was created using Microsoft Excel

† Second eigenvalue ratio is lower than 3 (value needed to be considered that the model is satisfied) because is influenced by a negative competence

Determining Cultural Competence Scores Among Participants

Cultural consensus analysis was used to determine the preferred (and hence reliable) responses to the 73 "true/false" items on the cultural consensus questionnaire, and to estimate the degree to which the participants agreed with each. The analysis was done using the analytical software package ANTHROPAC (Borgatti 1996). Cultural consensus analysis (see Table 1) was applied to the sample ($N = 80$); the model was satisfied with eigenvalue ratios = 29.33 and 5.94, mean competence = 0.58, SD = 0.21, $t = -2.5$, and one negative competence. In this study, females exhibited higher competence and agreement about the knowledge shared ($P < 0.5$). An unpaired-samples t test applied to competence means in the combined study population of DR and PR resulted in $p < 0.04$, indicating that the results are statistically significant.

Multidimensional scaling (MDS) converts resemblance into proximity, in order to render graphically the relationship among components of a model (Kruskal 1964; Kruskal and Wish 1978) such as our cultural consensus analysis. The measurement of the goodness of fit of the model of a given dimensional solution in MDS is referred to as "stress". High values of stress indicate a poor fit (i.e., a poorly mapped representation of the relationship calculated in the similarity matrix) whereas a stress value close to zero indicates a good fit. We used non-metric MDS as a further test of our cultural consensus analysis using agreement values of our study population ($N = 80$), with the software package UCINET 6 (Borgatti et al. 2002). We used the default settings of 2 dimensions to represent the values in Euclidean space. Calculated stress values for agreement (see Fig. 3) for each subgroup were 0.2 for DR and 0.1 for PR. These low stress values for agreement indicate that there was no significant diversity in competence within our study population, further supporting the results of the cultural consensus analysis.

The slight difference in stress values for agreement between DR and PR may have been caused by a single negative competence found in the DR study population (Table 1). This result should not be interpreted to imply that this one participant "knew nothing" or held ideas that were in total opposition to those of the other participants. Instead, it indicates that this

Table 2 Culturally-framed geological observations and interpretations

Questionnaire items	Response	
	Dominican Republic	Puerto Rico
It is likely that water can make rocks grow in number?	Y	Y
It is likely to find a unique relationship between my surrounding rocks and local plants?	Y	Y
It is likely to observe how rocks change in size over my lifespan?	N	Y
Are we likely to alter the growth rate of the rocks?	Y	Y
Are caves likely to be alive?	Y	Y
Are caves likely to have life within?	Y	Y
Are rocks likely to be alive?	Y	Y
Are rocks likely to grow?	N	Y
Are rocks likely to give birth?	Y	Y
Is the color of the rocks likely to tell me their age?	Y	Y
Are rocks likely to be changing faster than normal?	N	Y
Are rocks likely to be changing slower than usual?	N	Y
Are rocks like to move on their own?	Y	Y
Are rocks likely to be male entities?	Y	Y
Are rocks likely to be female entities?	N	N
Is likely to find caves with eyes of water?	Y	Y
Is likely to find caves with mouths of water?	Y	Y
Are rocks likely to give birth in water?	Y	Y
Are rocks likely to give birth in the land?	Y	Y
Are rocks likely to grow old?	Y	Y
Are caves likely to grow old?	Y	Y
Are the formations inside of caves likely to look like breasts that are dripping milk?	Y	Y

"Y" is used as a positive response or in agreement with the item asked, and "N" refers to a negative response. Responses are classified by country

one participant responded to the structured interview and the cultural consensus questionnaire more randomly. The responses provided by this participant did not fit with the mathematical model of the cultural consensus analysis, but this was an outlier. The competence averages and MDS results indicate that our cultural consultants knew the answers to the questions and tended not to guess randomly.

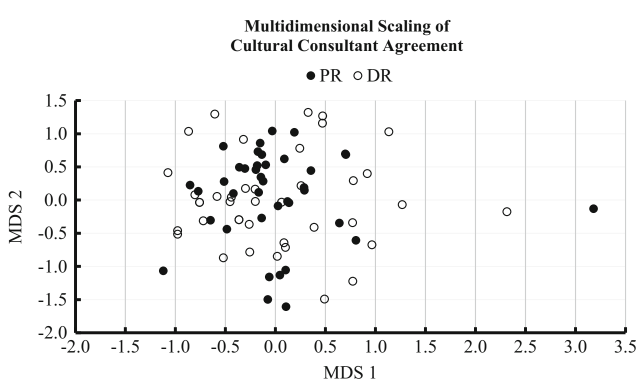

Fig. 3 MDS of cultural consultant agreement in DR and PR. Note: stress DR (0.2) and PR (0.1) is in two dimensions. Points closer together in space show more agreement about the cultural consensus model

Conceptual Key Elements of Local Ethnogeological Knowledge

Results from our cultural consensus analysis (competence scores, MDS, agreement values) indicate that there does exist an established CCM representing culturally framed ethnogeological knowledge about local karst processes and riverine geomorphology and held by inhabitants of the karst regions of DR and PR. The CCM encompasses the metaphors, similes, analogies, stories, and practices (agricultural, familial, ceremonial, etc.) used by the participants to describe and interpret noteworthy geological features and processes in karst terrain. Out of this statistically tested model of an ethnogeological knowledge system, we identify two recurrent themes that we refer to as conceptual key elements (CKE): representing geological knowledge that is gathered empirically (through

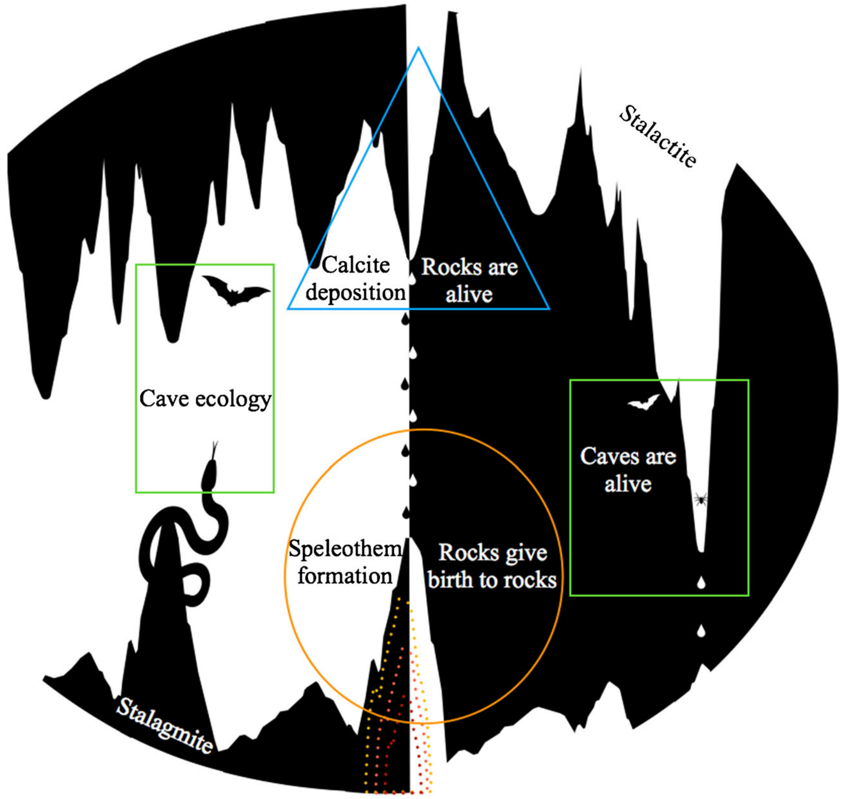

Fig. 4 Metaphors that cultural consultants used to describe processes that happen inside of caves. The CKE within the triangle is used as an analog to talk about the dissolution of limestone among other processes, the squares refer to cave inventory, and the circle to speleothem (specially stalagmite) formation in caves. Below the circle, dotted lines colored in red, orange, and yellow represent the timescale in the process of speleothem formation

observation, hypothesis, testing, etc.) but which is embedded in cultural knowledge that is shared among the entire population. CKE can be thought of as the "big ideas" of the system of ethnogeological knowledge that is represented by the CCM.

The first CKE we have identified is the idea that rocks are alive. This theme was further explored outside the cultural consensus questionnaire using participant observation and unstructured interviews. In general, this metaphor is used to describe the structure and integrity of rocks within an outcrop, and to describe the continuous process of carbonate dissolution and reprecipitation that forms speleothems in caves (see Fig. 4). This CKE encapsulates an understanding that rocks are active participants in dynamic processes of change observed throughout the karst regions of DR and PR.

The second CKE holds that rocks are able to grow and give birth to other rocks. This metaphor has been variously applied by participants to describe observed processes of mechanical weathering, erosion, and speleothem formation. For example, when cultural consultants described processes in riverine environments, they used the CKE to refer to wasting of terrain atop bedrock (rocks "grew" as they became more exposed). The common observation of a stalagmite forming by the steady drip of carbonate-rich water from an overhanging stalactite was also described in terms of a rock "giving birth" and "growing." We observed that the process of "growth" in rocks was adapted to different geomorphological scenarios among participants in DR and PR.

Many participants indicated that this type of knowledge, though based on personal experience, was generational and communal, and not exclusive to their own families (Unnamed participant, personal communication 2016). During our interactions with participants, they consistently offered further explanations and descriptions to support their responses to questions. In many instances, they introduced other metaphors for geological features and processes that could not be incorporated into this CCM, but which merit future study.

Discussion and Recommendations

This study should be viewed as a proof-of-concept rather than an exhaustive review of the ethnogeological knowledge of the inhabitants of the karst regions of DR and PR. On the basis of our results, we do endorse rapid-assessment ethnographic methods, combined with cultural consensus analysis, as a viable approach to productive ethnogeologic research in other communities and settings. Ethnogeological concepts from a CCM, expressed as CKE, can be used to render locally or regionally practiced formal and informal education (including geoheritage interpretation) more place-based, more culturally informed, and more locally relevant (e.g., Semken 2005; Reano and Ridgway 2015; Londoño et al. 2016). This, in turn, can bolster recruitment and retention of students from underserved and underrepresented communities with robust cultural and familial ties to land and environment (such as the *jíbaros* and *campesinos* of PR and DR), and enhance community interest in local geoheritage resources.

In order to even better apply ethnogeologic research to place-based formal or informal education, that goal should be deliberately integrated into the research design by including questions specific to teaching, learning, and interpretation (e.g., "What is most important for your children to understand about this landscape?" or "Which places are most useful for teaching people about certain natural processes?") in the preliminary free-listing and grand-tour stages. This approach would foster the organization of new ethnogeological knowledge in a CCM with the explicit purpose of generating CKEs as learning outcomes for formal or informal education, a commonly used approach known as backward design (Wiggins and McTighe 2005).

We also see potential applications for cultural consensus analysis in facilitating community-based participatory research relating to challenges to local and regional resilience and sustainability, such as cultural and environmental resource protection and management, natural-hazards preparedness and mitigation, and land-use decision-making. In the process of this study, we worked closely with local cultural organizations in both countries (*Higuayagua Taíno del Caribe* and *Naguaké*), and our cultural consultants and field assistants represented numerous different communities.

We have found that much of the knowledge shared by the participants already serves to facilitate the conservation of natural resources found in the karst regions in DR and PR. We observed that CKEs (e.g., caves and rocks are "alive" and that human influences can disrupt "growth" of rocks) were being used in messages related to conservation. We observed during fieldwork that caves and other elements of the karst landscapes were imbued with anthropomorphic features to appeal to the close relationship between the members of the communities and their home landscapes.

Limitations

Field-based ethnogeological research is laborious and takes time. The process of constructing the cultural consensus questionnaire required long hours of preparation by the research team and extensive communication with cultural experts. We made multiple visits to communities studied in order to build rapport with community members. Throughout the process, new knowledge was continuously accrued, but once the questionnaire was finalized and structured interviews started, cultural consensus analysis did not permit the addition of any new elements or domains of knowledge. Overcoming all of these limitations with longer periods of research would allow the construction of a more robust and comprehensive CCM with multiple elements relating to local or regional ethnogeological knowledge.

CCM yields competence scores and agreement values, but in its calculation, the model itself cannot distinguish between estimates of knowledge and actual knowledge. This limitation is in part because the model cannot distinguish between luck and expertise (Hruschka and Maupin 2013). Researchers should be aware that asking cultural consultants to engage with domains of knowledge unfamiliar to them will prompt guessing rather than informed responses, which the CCM cannot resolve. This problem can be addressed by developing a good rapport with and understanding of participants early in the study (as we did) or by involving community members in research design at the start, as is typical of participatory research.

Conclusions

In this paper, we discuss the application of rapid assessment methods and cultural consensus analysis, methods well-known in field ethnography, in a proof-of-concept study of ethnogeology of the karst regions of the Dominican Republic and Puerto Rico. Our cultural consensus model (competence and agreement values) represents a system of knowledge about karst and riverine features and processes held by the *jíbaros* of PR and *campesinos* of DR and shared between the two nations. Participants' observations and interpretations were culturally framed in a well-known system of references that are locally (geographically) situated and authentic to the population studied. We present two fundamental ideas (conceptual key elements) from the CCM relating to rocks in the study regions. These ideas are rendered in the form of metaphors, not unlike those used in mainstream science education to facilitate understanding of complex, time-integrated natural phenomena by non-experts (e.g., ocean currents work like conveyor belts of global temperature). This difference in the system of reference provides the community an understanding of their natural world in their own terms.

The results of this study suggest that elements of ethnogeological knowledge shared between the two nations have remained intact in spite of socioeconomic and political changes that have differentiated them in many ways. The idea of a widely shared (perhaps across the entire Caribbean basin) system of environmental knowledge has been explored in prior anthropological studies, but to the best of our understanding has not included ethnogeology.

It is very important to note that this study was not and is not intended to identify geoscientific "misconceptions" (from a mainstream scientific perspective) within the population studied. Our purpose was to test an approach to collecting, analyzing, and organizing culturally framed geological knowledge in the form of a model that can be used for purposes such as education. We sought only to determine the internal consistency (and hence trustworthiness) of the knowledge by developing a CCM, and thus to offer a template for further field-based ethnogeological research that can serve underrepresented cultural communities and their valued homelands through more place-based and culturally informed teaching, planning, decision-making, and stewardship.

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Appendix

Table 3 Free Listing Questionnaire

Question as administered in Spanish	English translation	Domain of knowledge
Escriba todos los usos que se le puedan dar una roca (piedra) que puedas recordar.	*Write down as many uses that rocks have as you think of.*	uses of local rocks
Escriba todos los colores de rocas (piedras) que puedas recordar.	*Write down as many colors of rock as you think of.*	textures of local rocks
Nombra todas las montañas que conozcas.	*Name all the mountains that you know.*	surrounding geography
Nombra todos los lugares en donde se puede encontrar agua que tu conozcas.	*Name all the places that you know where we can find water.*	karst hydrology
Nombra todos los nombres de los ríos que conozcas.	*Name all the rivers that you know.*	karst hydrology
Nombra todas las playas que conozcas.	*Name all the beaches that you know.*	surrounding geography
Nombra todas las cuevas que conozcas.	*Name all the caves that you know.*	uses of caves, surrounding geography
Escriba todos los usos que una cueva tiene que puedas recordar.	*Write down as many uses that a cave has as you can think of.*	uses of caves, karst hydrology
Escriba el nombre de todos los pueblos en su país que puedas recordar.	*Write down as many names of towns in your country as you can think of.*	surrounding geography

Table 4 Cultural Consensus Questionnaire

Question number	Question as administered in Spanish	English translation
1	¿Puede el agua almacenarse en las piedras?	*Can water be stored in rocks?*
2	¿Puede el agua viajar a través de las piedras?	*Can water travel through rocks?*
3	¿Puede la acción del agua hacer que las piedras se hagan más pequeñas con el tiempo?	*Can water make rocks smaller (dissolve rocks)?*
4	¿Puede la actividad humana cambiar los paisajes que observamos?	*Can human actions change the landscape that we observe?*
5	¿Puede la acción del agua cambiar el paisaje que observamos?	*Can water change the landscape that we observe?*
6	¿Puede la acción del agua hacer crecer las piedras en número?	*Can water make rocks grow?*
7	¿Puede la acción del agua hacer crecer las piedras en tamaño?	*Can the rocks that I see surrounding me be found anywhere in my country?*
8	¿Son todas las piedras que veo iguales?	*Are the rocks that I observe in my surroundings unique to this region?*
9	¿Son las piedras que veo alrededor de mi propiedad solamente de esta región?	*Does vegetation have a close relationship with the rocks?*

Table 4 (continued)

Question number	Question as administered in Spanish	English translation
10	¿Existe una relación única entre las plantas que observo a mi alrededor con las piedras?	*Can water flow underground?*
11	¿El agua corre debajo de la tierra?	*Can water flow through rocks?*
12	¿Puede la acción del agua romper la piedra para crear cuevas?	*Can water break the rocks to make caves?*
13	¿Son las cuevas importantes para mí?	*Are caves important for me?*
14	¿Son las cuevas importantes para mis vecinos?	*Are caves important for my neighbors?*
15	¿Son las cuevas importantes para mi familia?	*Are caves important for my family?*
16	¿Es el agua que debajo de la tierra la misma que encuentro en el río?	*Is the water underground the same as that from the closest body of water?*
17	¿Puedo observar como las piedras cambian en tamaño durante el transcurso de nuestra vida?	*Can rocks change in size during my lifetime?*
18	¿Pueden las piedras crecer en tamaño más rápido de lo que nosotros crecemos en tamaño?	*Can rocks grow faster than I?*
19	¿Pueden crecer las piedras más lento de lo que nosotros crecemos?	*Can rocks grow slower than I?*
20	¿Podemos nosotros alterar el crecimiento de las piedras?	*Can I change how rocks grow?*
21	¿Puede el agua formar cristales dentro de las cuevas?	*Can water form crystals inside of caves?*
22	¿Las cuevas están vivas?	*Are caves just holes in the ground with no life?*
23	¿Tienen las cuevas vida adentro?	*Do caves have life inside?*
24	¿Las piedras están vivas?	*Are caves alive?*
25	¿En esta área las cuevas tienen agua?	*Are rocks alive?*
26	¿Puede el agua mover los materiales para hacer cristales dentro de la cueva?	*Do all caves have water inside?*
27	¿En esta área las cuevas están secas adentro?	*Are all caves dry?*
28	¿Cambian de forma las cuevas con los años?	*Do caves change through the years?*
29	¿Pueden cambiar las cuevas durante el transcurso de nuestra vida?	*Do caves can change in my lifetime?*
30	¿Están cambiando las cuevas a la misma vez que nosotros envejecemos?	*Do caves change in the same time that I change?*
31	¿Están cambiando las cuevas más rápido de lo que nosotros envejecemos?	*Are caves changing at a faster rate in comparison to how I get old?*
32	¿Están cambiando las cuevas más lento de lo que nosotros envejecemos?	*Are caves changing at a slower rate in comparison to how I get old?*
33	¿Pueden las piedras cambiar el sabor del agua?	*Can rocks change the flavor of water?*
34	¿Pueden las piedras hacer el agua más limpia?	*Can rocks clean the water?*
35	¿Pueden las piedras mantener el agua limpia?	*Can rocks maintain clean water?*
36	¿El agua que viene del pozo es más segura para tomar que la que viene del río?	*Is the water coming from the well cleaner than the water from the river?*
37	¿El agua que viene del pozo es más segura para tomar que la que viene del acueducto?	*Is the water coming from the well safer than the water from the aqueduct?*
38	¿Pueden las piedras cambiar de forma?	*Can rocks change their form?*
39	¿Puede ayudar el viento a aumentar en número de las piedras en tierra firme?	*Can wind help in the multiplication of rocks?*
40	¿Puede ayudar un huracán a aumentar el número de las piedras?	*Can hurricanes help in the multiplication of rocks?*
41	¿Puede ayudar el pasto a aumentar en número de las piedras?	*Can grass (vegetation in general) help in the multiplication of rocks?*
42	¿Tienen todas las piedras el mismo origen?	*Do all rocks have the same origin?*
43	¿Todas las piedras tienen el mismo color?	*Do all rocks have the same color?*
44	¿El agua que esta debajo de la tierra es la misma que el agua que viene de la lluvia?	*Is the water coming from the sky the same as the water found underground?*
45	¿Las piedras crecen?	*Do rocks grow?*
46	¿Las piedras paren?	*Do rocks give birth?*
47	¿La forma de las piedras me dice su edad?	*Can I see how old rocks are by looking at their form?*
48	¿El tamaño de las piedras me dice su edad?	*Can I see how old rocks are by looking at their size?*

Table 4 (continued)

Question number	Question as administered in Spanish	English translation
49	¿El color de las piedras me dice su edad?	*Can I see the age of the rocks by looking at their age?*
50	¿Están cambiando las piedras últimamente más rápido de lo normal?	*Are rocks changing lately faster than normal?*
51	¿Están cambiando las piedras últimamente más lento de lo normal?	*Are rocks changing lately slower than normal?*
52	¿Están las piedras echas de diferentes materiales?	*Are rocks made of different materials?*
53	¿Son las piedras color claras mejores para cocinar en un fogón?	*Are light-colored rocks better for cooking?*
54	¿Son las piedras color obscuras mejores para cocinar en un fogón?	*Are dark-colored rocks better for cooking?*
55	¿Las piedras se mueven?	*Can rocks move?*
56	¿Las piedras se mueven dentro del agua mejor que en la tierra firme?	*Do rocks move better on water than in land?*
57	¿Las piedras son masculinas?	*Are rocks males?*
58	¿Las piedras son femeninas?	*Are rocks females?*
59	¿Hacen las piedras el agua más pura?	*Can rocks make water purer?*
60	¿Se pueden conectar las cuevas con otras cuevas?	*Can caves connect with other caves?*
61	¿Se pueden conectar las cuevas con la playa?	*Can caves connect with the beach (ocean)?*
62	¿Fueron las cuevas importantes para mis ancestros?	*Were caves important to my ancestors?*
63	¿Las cuevas tienen mensajes de parte de mis ancestros?	*Do caves have important drawings from my ancestors?*
64	¿Las cuevas tienen que protegerse?	*Do we need to protect the caves around me?*
65	¿Hay cuevas que conectan con ríos?	*Can caves connect with rivers?*
66	¿Existen cuevas con ojos de agua?	*Do caves have springs?*
67	¿Existen cuevas con bocas de agua?	*Do caves have rivers?*
68	¿Las piedras paren en el agua?	*Can rocks give birth in water?*
69	¿Las piedras paren fuera del agua?	*Can rocks give birth free of water (dry)?*
70	¿Las piedras envejecen?	*Do rocks grow older?*
71	¿Las cuevas envejecen?	*Do caves grow older?*
72	¿Existen formaciones dentro de las cuevas parecen senos botando leche?	*Can we find formations that look like "breasts" dripping milk inside of caves?*
73	¿Cuándo llueve fuera de la cueva estas formaciones crecen?	*Do these formations grow when it is raining outside?*

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