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Ethnogeology in Amazonia: Surface-water systems in the Colombian Amazon, from perspectives of Uitoto traditional knowledge and mainstream hydrology

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ABSTRACT

Ethnogeology, the scientific study of geological knowledge of groups such as indigenous peoples, can be combined with mainstream geological sciences to enhance our understanding of Earth systems. The Amazon rain forest has been extensively studied by both mainstream scientists and indigenous researchers. We argue that knowledge of Amazonian geology and hydrology held by indigenous Uitoto experts is valid, empirically based, and, in many cases, more nuanced than mainstream scientific knowledge. We also argue that knowledge sharing between mainstream and indigenous researchers can improve geological and environmental knowledge on both sides and provide solutions for current environmental problems such as increased pressure on water resources and global warming. We applied methods from ethnography and earth science to examine the traditional ecological knowledge of an Amazonian tribe in Colombia, the Uitoto, about water, and how that knowledge correlates with that of mainstream earth scientists. The study demonstrates how ethnogeology can be applied in a water-rich environment to: (1) compare knowledge about the natural history of an area, (2) study the geological resources available and their uses, and (3) examine the bases of native classification schemes using mainstream science methods. We found parallels and complementary concepts in the two bodies of knowledge. Our results suggest that the Uitoto have a meticulous taxonomy for water and wetlands—knowledge that is essential for protecting, conserving, and managing their water resources.

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INTRODUCTION

Indigenous peoples acquire and pass on knowledge about their environments over hundreds of years. Their environmental knowledge is a subset of a broader system of knowledge variously referred to as traditional ecological knowledge (TEK), native science, native ethnoscience, or local knowledge. The epistemological correspondence between such systems of knowledge and that of mainstream (also western and Eurocentric) science has long been debated (e.g., Snively and Corsiglia, 2001; van Eijck and Roth, 2007; El-Hani and Bandeira, 2008; Brayboy and Castagno, 2008; Aikenhead and Michell, 2011). Regardless, traditional geological knowledge has historically served tribal peoples in many of the same ways that mainstream geology serves modern civilizations, for example, in cross-generational awareness of potential volcanic hazards by Native Americans in Cascadia (Barber and Barber, 2004), in locating subsurface metal ores in ancient China (Tang, 1984), and in managing limited water resources in the arid Puebloan lands of North America (Snead, 2006). The geological knowledge compiled by past and present indigenous societies in some localities has proven useful in modern geophysical (Ludwin and Smits, 2007) and climatological (Maldonado et al., 2014) research, and ethnogeological methods have been used to interpret cultural knowledge relevant to urban water-management policy (Gartin et al., 2010).

Ethnogeology (Kamen-Kaye, 1975; Murray, 1997; Semken, 2005) is the scientific study of relationships between peoples and Earth's systems (i.e., Earth's materials, structures, processes, resources, hazards, and history; Kamen-Kaye, 1975; Murray, 1997; Semken, 2005). It has the potential to meet challenges of cultural and environmental sustainability, particularly in contested or threatened places (e.g., Semken and Brandt, 2010). For example, the ethnogeologic study of key natural resources, such as surface water, can inform plans for conservation, protection, sustainable use, and management on tribal lands.

In this paper, we argue that indigenous geological knowledge is valid, is empirically based, and correlates with mainstream scientific knowledge, which can be enhanced by thoughtful consideration of native systems of knowledge characterized by ethnogeology. Our case study of traditional Uitoto knowledge about the tribe's water-rich ancestral lands in the Amazon rain forest provides evidence for our argument and suggests that indigenous knowledge about hydrological systems can complement western scientific knowledge. Similarly, in this time of rapid climate change, bodies of mainstream knowledge and technology may be useful to native peoples for resource management.

Uitoto Traditional Knowledge

Traditional, specialized knowledge is orally transmitted by the Uitoto[1] in a nighttime ritual, the *mambeo* (Urbina Rangel, 1988; Echeverri, 1997), during which two plant-based preparations are consumed, *mambe* and *ambil*. *Mambe* is composed of powdered coca leaves (*Erythroxylum coca*) and ash from a tree (*Cecropia* sp.). *Ambil* is tobacco paste mixed with different kinds of vegetable salts (Echeverri and Roman, 2011). Uitoto tradition holds that these two preparations, properly used, induce increased focus, memory, intelligence, and alertness.

Knowledge transmitted during the ritual covers a variety of topics, including nature and its phenomena and why the elements behave in one way and not in another (Corredor, 1986). Detailed knowledge of place is essential to peoples who make their living by foraging, fishing, and/or horticulture, and the Uitoto know their environment intimately. The cultural specialist may also address ethics and proper behavior toward oneself, others, and the environment (Urbina Rangel, 2010). The theories learned in the nighttime are practiced during the day. This is expressed as the "dawning of the word," the word spoken should be seen, become concrete, in the form of an action or product.

Traditional Annual Ecological Cycle

The Uitoto ecological calendar is based on the moon cycle; 13 full moons in a year are grouped into 12 periods (one of the periods has two full moons). The 12 periods are divided into four seasons: two summers and two winters, each with different length. Each season is characterized in terms of precipitation, temperature, plants that blossom or bear fruits, animal behavior, and prevalence of diseases (Makuritofe and Castro, 2008). Here, we present the most salient characteristics of the seasons with emphasis on water resources.

(1) *Yarímona* (cicada summer): This is the beginning of the traditional annual cycle; it roughly corresponds to October and November. Temperatures are high ,and thunderstorms are common, and although rain events can last for up to 3 d, this is a relatively dry season. The river level rises and falls. Viruses, parasites, and diarrhea are common diseases at this time. This season is also known for the different worms, maggots, and grubs in the environment. Thus, it is perceived as a time of disease for both the environment and people, and certain behaviors need to be observed to prevent disease.

(2) *Pɨmóna-Uáikɨ* (summer harvest; rain): During this season, certain palms and trees bear fruits, marking different times of the summer. This is harvesting time. The first part of the summer is the driest of the annual cycle, and the river decreases to its lowest level (December–January). Winds blowing from the east are gentle. During March, precipitation increases and continues through April and May. The river starts to steadily rise for the first time in the annual cycle. Various water bodies interconnect, forming avenues for aquatic species. Fruits and flowers fall into the water of the flooded forest, providing food for fish and

[1] Uitoto, also spelled Witoto and Huitoto, has four related dialects, one of which, *Nɨpode*, is spoken in our study area. We adopt the spelling developed by Griffiths et al. (2001), which is endorsed by the Uitoto *Nɨpode*. In the orthography of Uitoto, there is frequent use of the i vowel barred [ɨ], a high central vowel, pronounced similar to English "just" for some speakers. In this paper, we use italic and underline for words in Uitoto and italics for words in a language other than English. Proper names are not italicized.

animals. Fish lay their eggs in channels. Toward the end of the season, the precipitation decreases, and temperatures increase.

(3) *Riakɨ* (reproduction time): This is the time when most animals reproduce (June and July). Fruit is abundant until the beginning of the wintertime, thanks to the rain received in the previous season. The river first rises rapidly and then recedes.

(4) *Nókɨ*-*Rótti* (winter and cold time): This season includes four lunar cycles, two of which are named after plants that bloom (green *Guacarí* and tobacco), and two of which are named after the weather (gentle rain and *friaje*). (*Friaje* is a climatic phenomenon produced by the advance of a cold front and high-speed winds, which cause a temperature drop of 10–20 °C.) It is a time of strong wind, thunderstorms, and rain. The pervasive rain causes the water levels to rise, and the last annual flooding of the river occurs during this time (August and September). The flooding event is called the *Canangucho* flood because it coincides with the ripening of the fruit of the *Canangucho* palm, or *Kɨnére* (*Mauritia flexuosa*). After this season, the calendar starts again.

Indigenous people of the Amazon have observed how their finely tuned traditional calendars do not predict the events as well as they formerly did (Makuritofe and Castro, 2008; Londono, this study). Mainstream researchers have used the detailed calendars to investigate the offsets produced by climate change in the Amazon Basin (Kronik and Verner, 2010). For example, the *friaje* begins and ends earlier, it is warmer, and its winds are milder. For the indigenous people of the Amazon, the *friaje* revitalizes and cleanses the jungle, and it is in itself a diagnostic of the wellness of the forest: A weak *friaje* means a weakening of the entire ecological system (Kronic and Verner, 2010).

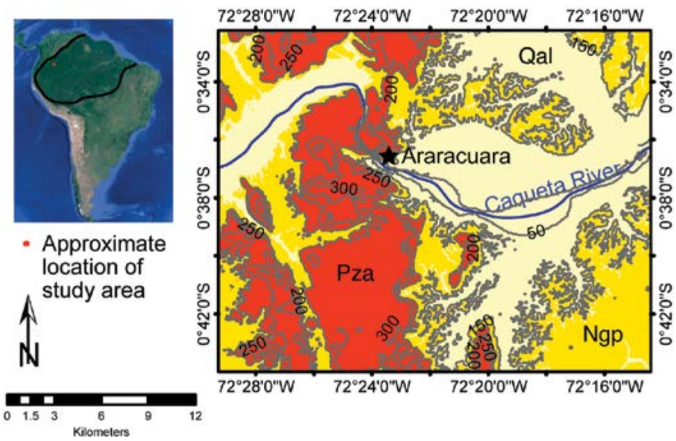

Figure 1. Location and geology of the area of study. Araracuara is located on the north bank of the Caqueta River in Colombia, northwest Amazon Basin. Geology: Qal—Quaternary alluvial, Ngp—Neogene (Eocene–Miocene) Pebas Formation, Pza—Paleozoic Araracuara Formation. Figure is after: Geologic Map of Colombia (INGEOMINAS, 2007).

METHODS

We applied research methods from two sciences (geology and anthropology) to conduct a case study of Uitoto traditional knowledge. We consulted with the regional and local indigenous authorities: the Regional Indigenous Council for the Middle Amazon, and the Araracuara government. We obtained and documented informed consent from all the participants involved in the study. The study was approved by the Institutional Review Board of Arizona State University and complies with the Research Ethics guidelines of the National University of Colombia.

Study Site

The Amazon Basin has a tropical-equatorial climate. Mean temperatures range between 24 °C and 26 °C, with annual precipitation between 2500 and 3000 mm (IGAC, 2002). Precipitation shows a peak between March and May and a dry season between January and February (Corpoamazonia, 2008). The climatic region is tropical rain forest, the Thornwaite humidity index is 61%–80%, and the relative humidity can reach 85% (IGAC, 2002).

Our study site is Araracuara, Colombia, located on the south bank of the Caqueta River (Fig. 1; Japura River in Brazil), a main tributary of the Amazon.

Selecting Participants and Indigenous Coresearchers

To learn from the Uitoto environmental knowledge, we used expert sampling, a kind of purposive sampling (Bernard, 2002). Purposive sampling is a nonprobabilistic technique in which a particular characteristic of the population is selected according to the purpose of the study. In this case, we found two Uitoto elders, renowned cultural specialists: the late Vicente Makuritofe and Marceliano Guerrero. Acknowledging that the Elder Vicente Makuritofe contributed most of the content of this manuscript, he appears as a coauthor in this work. He and five of his extended family members participated actively in this research.

To study traditional knowledge about water and to collect samples, we conducted field research during the months of January 2012 and August 2014. In between field seasons over the course of 2 yr, we interviewed our collaborators in Araracuara, Bogota, and over the phone using unstructured and structured interviews (Bernard et al., 1986). To collect ethnographic data in Araracuara, we used a participatory rapid-assessment (PRA), as described in Bernard (2002). We collected stories related to rivers or water bodies that could code environmental information. In the field area, the native coresearchers guided the field trips and drew maps of their territory and the rivers or water bodies important to them (Fig. 2). Native researchers conducted field research in August 2014, they collected and sent water samples, and they were interviewed over the phone.

Water Sampling and Analysis

In Araracuara, native participants selected and sampled five different types of water using categories of their own (*churuŕapo*, *imáni*, *jíruebɨ*, *jɨ-dɨye*, and *kɨnére*; Table 1). The water samples were collected in August 2014, when the main flood (*canangucho* flood) was receding but water levels were still high. Samples were

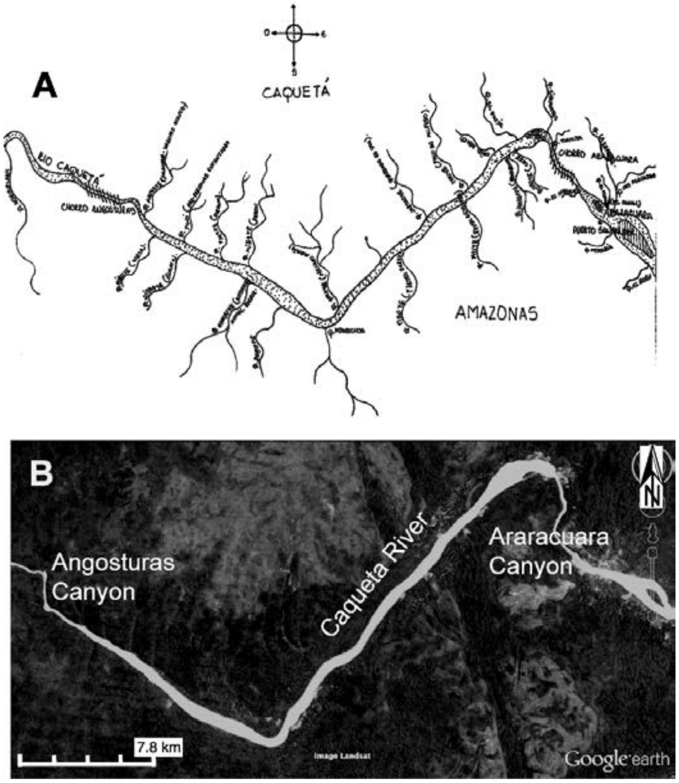

Figure 2. Participatory mapping can produce maps that are comparable to satellite imagery or official cartography, but that contain more local information. (A) Map showing the names of the rivers between Angosturas and Araracuara canyon with their names in Uitoto <u>*Nɨpode*</u> and Spanish. The locations of Caqueta and Amazonas Departments (equivalent to states) are shown. Drawn by Vicente Hernandez, Uitoto researcher. (B) Landsat image of the same area showing the detail of river morphology attained by the author.

located on a map by native (Hernandez M. and Hernandez T.) and nonnative scientists (Londono and Garzon); the approximate locations of sample sites are shown in Figure 3.

To test if the water samples pertained to different western science categories, we analyzed the chemistry of the water and performed statistical analysis to identify the underlying structure of the data. One liter aliquots of water were collected in high-density polyethylene bottles. Each type of water was sampled in triplicate, for a total of 15 samples (15 L). The native researchers measured the pH of the water in the field using a colorimetric test and wrote the value on the bottle with permanent ink. They also included the date and name of the water in Uitoto <u>*Nɨpode*</u> and in Spanish, if applicable. The samples were kept in the shade and air-shipped to Bogota in a cargo plane within 2 wk. Upon receipt, the pH and Eh of samples were measured. Samples were filtered through two syringe filters (1 µm and 0.2 µm) into two 100 mL high-density polyethylene bottles, one to measure cations and one to measure anions. The prepared samples were preserved cold.

Laboratory analyses of the water samples were conducted at Arizona State University. The concentration of major ions was determined by means of ion chromatography. Undiluted samples were run in a DIONEX DX 600 IC system. The anions measured were F^-, Cl^-, NO^{2-}, Br^-, NO^{3-}, SO_4^{2-}, and PO_4^{3-}. The cations measured were Na^+, K^+, NH_4^+, Mg^{2+}, and Ca^{2+}. Blanks were included. Principal component analysis (PCA) was performed using R software (R Core Team, 2013) on 15 water samples.

Hydrology

We mapped the surface runoff with digital elevation models (DEMs, 90 m resolution) and geographic information systems.

TABLE 1. FIELD AND LABORATORY DESCRIPTIONS OF FIVE WATER TYPES

Uitoto	English	Field description (provided by co-researchers)	Laboratory description	pH	Cond. (µS)
Churúrapo	Spring	Water comes from a spring, a hole in the dirt. The terrain does not have stones or rocks, there is no root mat, and the water comes from the dirt (*tierra*), not from clay. The water is crystalline, and is cold.	Clear water with high transparency and mud odor. Dark particles at the bottom of the bottle, probably organic matter.	5.3	11.1
Imáni	Big river	The water was collected from the Caqueta river (<u>*Uígonamani*</u>). The river brings all the dirt from the cordillera.	Yellowish, medium transparency. Clay-sized particles and white particles in suspension.	66.7	19.5
Jíruebɨ	Muddy water	This water comes from a muddy place that has red, acid mud (<u>*ellikie*</u>); the mud is used for medicinal purposes. The water flows out of the mud, is a small spring. The water gets filtered in that mud and is good to drink. Collected near the boarding school.	Clear water, associated with red mud. Odorless.	5.4	18.6
Jɨ̄diye	Black water	This water was collected from a small dam on a black water creek (*Las Mercedes*). The creek starts in the rocks, boulders, near the airplane strip, but the source of this water is the rain. This type of black water picks up all that is in the environment, vegetal material, the dirt that comes from the trees. It is not good to drink but it can be used for allergies on the skin.	Light yellow with yellow particles in suspension likely from plant origin. Earthy smell.	5.0	10
Kinére	Palm swamp (*Mauritia flexuosa*)	Water from a *cananguchal* (palm swamp) about a day walk from the village. The water is clear. The *cananguchal* is big, long, there are plenty of animals. There are no creeks around. The forest is high around it.	Clear water. Yellow particles in suspension of vegetal origin. The sample contained a seedling that was identified as *Mauritia flexuosa*.	5.5	9.76

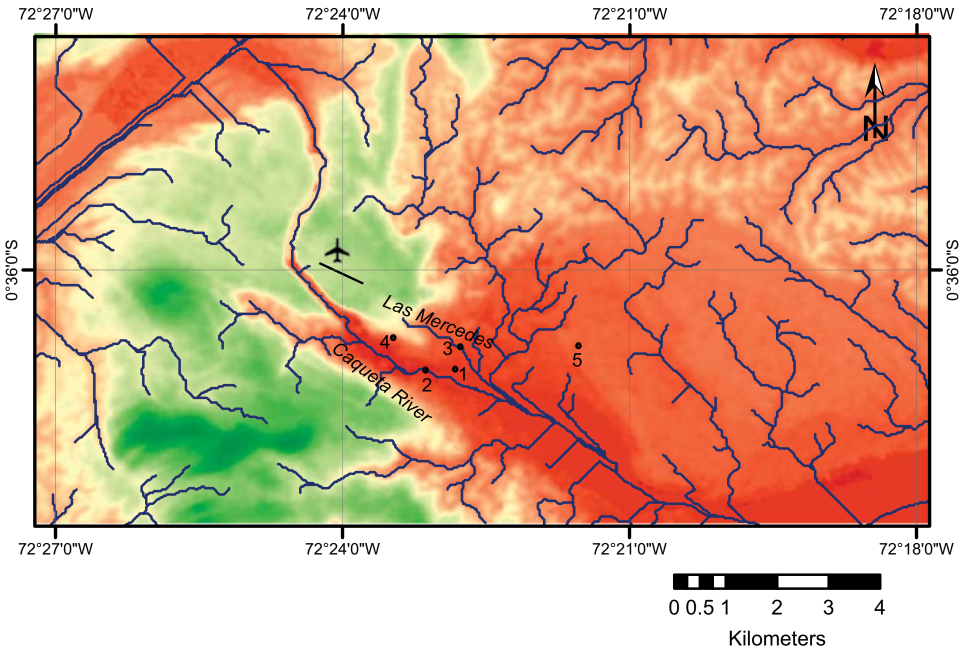

Figure 3. Hydrology map of Araracuara and location of sampling sites. 1—*Churrapo* (spring), 2—*Imáni* (main river), 3—*Jíruebɨ* (muddy water), 4—*Ji¯diye* (black water), 5—*Kinére* (*Mauritia flexuosa* palm swamp). Sampling site locations are approximate (see text for details). The drainage network was generated from a digital elevation model using TauDEM (Tarboton, 2003) and ArcGIS and ArcMap (ESRI, 2011).

Stream maps were generated using TauDEM tools (Tarboton, 2003) in ArcMap (ESRI, 2011; see Fig. 3).

RESULTS AND DISCUSSION

Birth of the Amazon: Uitoto Oral History versus Mainstream Geoscience

The predominant scientific model of the origin and evolution of the Amazon River was comprehensively presented in the book *Amazonia: Landscape and Species Evolution*, edited by Hoorn and Wesselingh (2010), and is briefly summarized here. Before the Miocene Epoch, the topography and structure of the Amazonian craton (Archean to Mesoproterozoic; Kroonenberg and de Roever, 2010) controlled the fluvial systems of western Amazonia. During the early Miocene (ca. 23–16 Ma), the cratonic rivers were replaced by lakes, swamps, tidal channels, and a marginal marine embayment in the north (Fig. 4A). Continued uplift of the northern Andes sealed the connection of the lowland with the Pacific and the Caribbean. During the late Miocene (ca. 11–7 Ma), the hydrology of the Amazon Basin was dominated in the east by rivers and tides and in the west by lakes and wetlands, forming a complex environment that supported considerable biodiversity (Fig. 4B). From 11.3 Ma onward, Andean sediments reached the Atlantic and built the Amazon delta. The transcontinental Amazon system as we know it today was probably established around 7 Ma, and it is represented in Figure 4C (Hoorn et al., 1995; Figueiredo et al., 2009).

The Uitoto story of the origin of the Amazon has also been referenced in the literature (Urbina Rangel, 1988; Garzon and Makuritofe, 1990; Preuss, 1994; Henao, 1996; Urbina Rangel, 2010). Preuss (1994) collected an extensive corpus of Uitoto folktales, which have provided the basis for later linguistic and cultural analyses (Petersen de Piñeros, 1994). We collected the story and present here an abbreviated version. The story is also depicted graphically in Figure 5.

"That River was a tree, the *Moníya aména*, tree of abundance. The tree had a lake at its base that grew along with the tree. The tree produced a great variety of fruits and foods. Its abundance was so great that it produced plenty to feed all the peoples; the animals were the people of that time. However, the tree and the lake continued to grow, the tree reached impossible heights, and the lake covered vast areas. Even the flying and the swimming animals struggled to reach the food. At that point the animals agreed that, if they were to eat, they had to chop down the tree. When the animals were cutting it, the splinters and chips of wood formed different fish. From the bark came the octopus, the pink dolphin, the sea cow (manatee), and others. When the tree fell, its trunk formed the *Moníyanamani* (Amazon River), the tree of abundance. The branches formed the main tributaries, and small twigs formed creeks and gullies" (narrated by V. Makuritofe; Londoño, this work).

Most native stories represent scientific thought and its applications metaphorically (Cajete, 2000). The tree of abundance is such a metaphorical representation and a crosscutting theme in Uitoto knowledge. Fully narrated as a chant, the story requires several nights to complete. The myth has been shown to code information for plant evolution and taxonomy (Garzon and Makuritofe, 1990), social evolution and agriculture (Henao, 1996), and the evolution of the Amazon Basin (Garzon and Makuritofe, 1990; Urbina Rangel, 2010). This study is the first to reference the story to geoscience. We presume that other taxonomies of natural systems and processes (e.g., fluvial systems, animal coevolution) may also be embedded in the *Moníya aména* narrative.

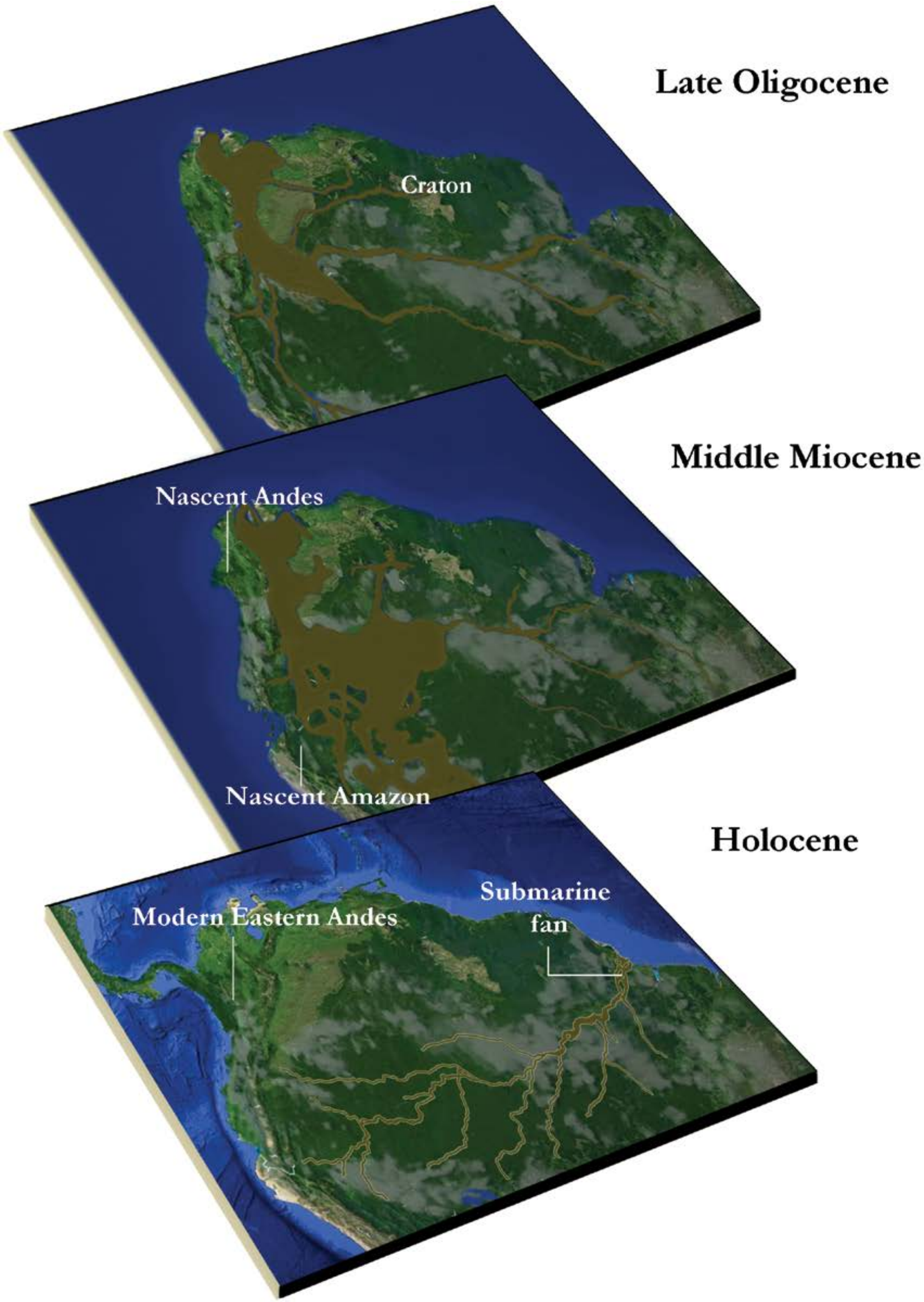

Figure 4. Representation of the geologic evolution of the Amazon River encompassing the evolution of the landscape and species. (A) In the early Miocene, the northern Andes were not uplifted. The Amazon craton topographically controlled the Amazonian drainage, and the main flow direction was toward the north and northwest. (B) The development of a megawetland in the middle Miocene was a consequence of the nascent northern Andes, which forced water down their eastern slopes and closed the NW outlet of water. (C) The Amazon River today flows towards the east, connecting the Andes and the Atlantic Ocean. Figure is adapted from Hoorn (2006).

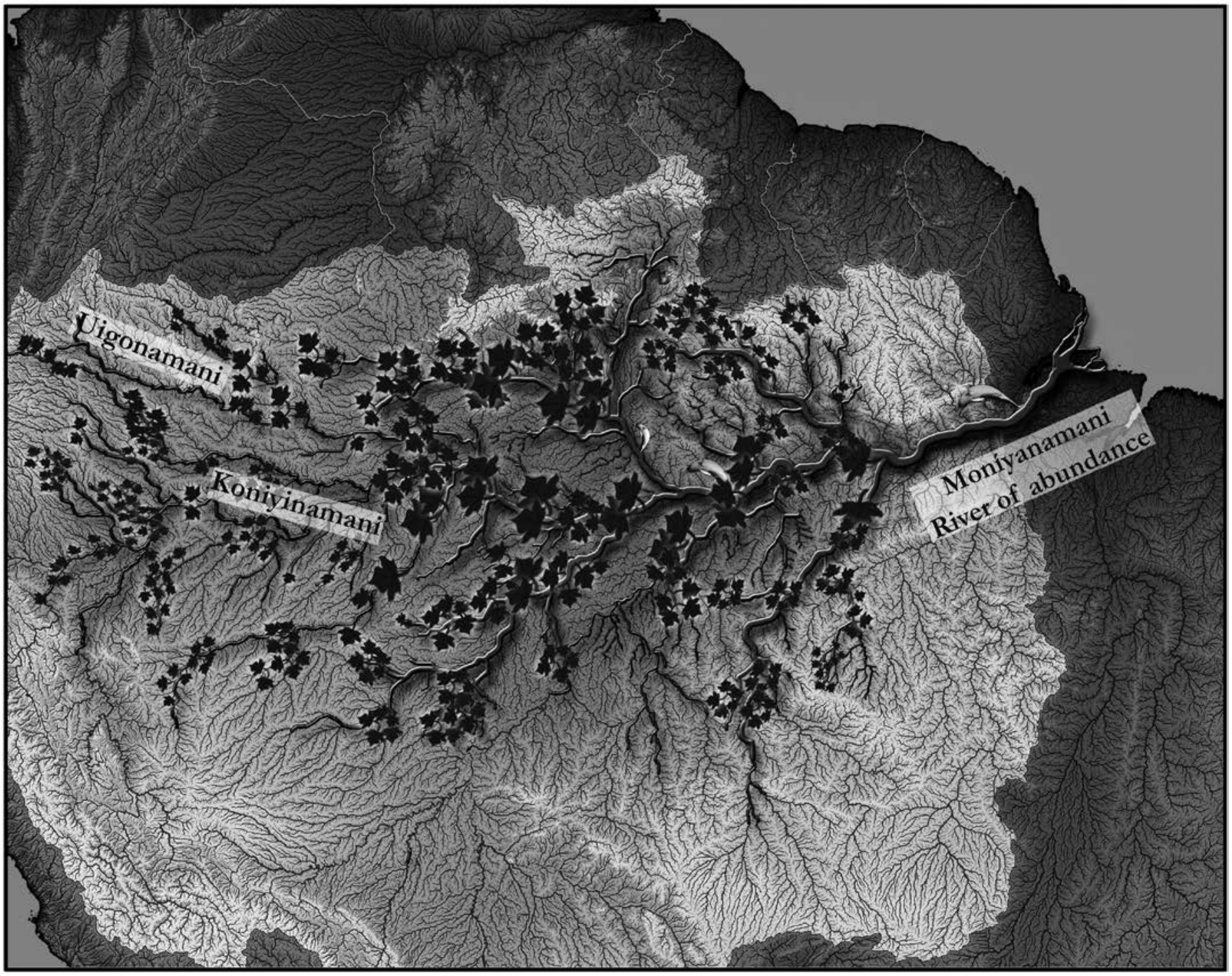

Figure 5. Representation of the *Moníya amena* story: Uitoto metaphor that explains the Amazon River system as a big tree that was felled and imprinted its shape on the land. The *Uígonamani* (Caqueta River) and *Koniɨinamani* (Putumayo River) are main branches of the tree. Animals like the pink dolphin came out from its trunk.

Several useful parallels between mainstream geology and the *Moníya aména* narrative can be drawn, suggesting that this story could be particularly useful for place-based and culturally informed geoscience teaching. The principal points of commonality are:

(1) Amazonia was partially flooded. Mainstream geoscientists agree that during the middle to late Miocene (16–11 Ma), western Amazonia was occupied by a "megawetland" (Hoorn et al., 2010). In the *Moníya aména* story, an immense lake extended at the base of the tree; the *Moníyamena jórai* was "a very big lake, like a sea, that will later form the rivers and lakes of the entire region" (Garzon and Makuritofe, 1990, p. 119). In other words, the megawetland appears to correspond to the *Moníyamena jórai*.

(2) The flooded area in western Amazonia evolved into a river system that resembles a tree. Tectonic uplift of the northern Andes ended the flood and redirected the flow of water into an interconnected drainage system. In geomorphology, the tree-shaped drainage networks are called arborescent or dendritic. In the Uitoto story, the felling of a colossal tree put an end to the lake and imprinted a tree shape onto the land.

(3) The Amazon is a biodiverse and interconnected ecosystem. The species that have occurred along with the development of the Amazon River have been studied by mainstream palynologists, paleobotanists, paleontologists, and molecular phylogeneticists (Hoorn and Wesselingh, 2010). The Uitoto "Tree of Abundance" story explains how animals and plants diversified and coevolved with the landscape. Many animals originated from parts of this biodiverse tree: octopus from the root, massive aquatic animals from the bark and trunk, fish from wood splinters and from fruits.

An evolutionary pattern or explanation seems to be engraved in the structure of the story. However, at a more basic level, we posit that the *Moníya* *aména* story would be an appropriate framework upon which to organize curricula for place-based teaching of the geology and natural history of the Amazon Basin. The story provides local and highly relevant cultural context for teaching mainstream scientific concepts related to the Amazon Basin.

(4) This same approach has been used successfully to teach geoscience in other indigenous communities (e.g., Semken and Morgan, 1997; Semken, 2005).

Mainstream natural scientists from diverse disciplines, including geology, biology, botany, climatology, and ecology, have only recently begun to collaborate across disciplines in order to better understand the evolution of Amazonia. Indigenous scientists have long used a strongly holistic (transdisciplinary) approach in order to interpret the intricate Earth system interrelationships within their home environments and landscapes, and to understand how those interrelationships influence the lives of their communities (Cajete, 2000). This is an appropriate time for mainstream and native scientists to ally in common pursuit of better understanding of, and more sustainable coexistence with, the global Earth system.

Water Taxonomy

Schemes used by indigenous and local peoples to classify water features in the landscape are diverse, especially in a water-rich environment such as the rain forest. In the Amazon Basin, rivers are classified by color. The color-based names of Brazilian rivers (e.g., Rio Preto [black], Rio Claro [clear], Rio Branco [white], and Rio Verde [green]) may be Portuguese adaptations of a preexisting native nomenclature (Junk et al., 2011). Wallace, a British explorer and naturalist, introduced the color-based classification for Amazonian rivers into mainstream science (Wallace, 1889, p. 281). He classified the rivers as "the white-water rivers, the blue-water rivers, and the black-water rivers." It seems likely that he borrowed these classifications from the Portuguese names. Sioli (1956, 1984) popularized Wallace's three-color classification scheme. Whitewater rivers originate in the Andes and transport nutrient-rich sediments. Blackwater rivers are born in the Guiana Shield: Their suspended load is poor in nutrients and high in humic acids and organic compounds (Duncan and Fernandes, 2010). Clearwater rivers drain the central Brazilian Shield and are only found in the Middle Amazon (Junk et al., 2011)

Like hydrologists, the Uitoto classify the water by colors. They attribute a river's distinct color from the "rocks and mud" present at its source and along its course. Native classifications include the colors of the animals that live in and along the rivers; it is more detailed than the standard Eurocentric classification.

The large rivers in Colombia, Amazonas (*Moníyanamani*), Caquetá (*Uigonamani*), and Putumayo (*Koniyɨnamani*) are from ash waters (*Uigogɨn*-*uigorende*). Mud-colored animals inhabit them. White water or white creeks (*Utegin*-*Uteye*, *Nogora*) are crystalline waters; they are very rare because they are born of white land and rocks (*Ogonɨe*), and they come with white sand. Gray-mud water (*Giruegɨn*) and brown water (*Gitɨgin*) come from brown ground (*Gitɨnɨene*). Everything produced in that water—plants, fish, frogs, and crickets—all are brown. Red waters (darker variety) (*Giayen*-*giagin*) are born from reddish lands; green waters (*Mocogin*-*mocoye*) emerge from green or blue lands, and they also have their corresponding-colored animals and beings. It is necessary to know where the creeks or small rivers come from—that is what makes them different; for example, red (bright and intense red) waters (*Ecogin*-*ecolege*) are very scarce in the territory, because they are of tigers, they are not born on Earth, and they come from the history of peoples from *Moo*-*Buinaima*, from *Muina* world (Elder Marceliano Guerrero Jekone, Garzon, personal commun., 2014).

The Uitoto names for certain water bodies describe the characteristics recognized by mainstream science. For example, the Amazon is the *Moniyanamani*, (from *monie*: abundance, also to have food in abundance, and *Imáni*: large/main river). Thus, the name translates as "large river of abundance," alluding both to the abundance of species and of nutrients (food) particular to the river. For the Uitoto in Araracuara, the Caqueta River is the *Uigonamani*, from *uigo*, which means dirt, thus the "large muddy river." The Putumayo is the *Koniyɨnamani*, or the "large sandy river." This name not only refers to the load but to the extensive sand beaches that the Putumayo River forms. In other words, the Uitoto names refer to characteristics that are salient to both indigenous and mainstream observers.

Not all the classification schemes of native science correspond to those of mainstream science. Native management of water is based on classifications ranging from mythical discourse to socioeconomic, environmental, and medicinal applications. For example, Uitoto stories about the "river of creation" (*Komuiya Namani*), the source of surface and groundwater, is another way of classifying water. This classification includes categories such as *Nofidai* *namani*: stone water; *zafidai* *namani*: water of sands, which is medicinal and sacred; *erigɨnamani*: bitter water; *rochidai namani*: acidic water; *jucure* *namani*: poisonous water; *jitɨrue namani*: black water; *nonokɨnamani*: achiote (*Bixa orellana*) water; *mɨkɨgɨi* *namani*: harmful water. The Uitoto describe and characterize each water body in their territory according to intricate traditional knowledge that mainstream scientists do not yet understand. This paper offers an introduction to some of that knowledge, which could be compared to and integrated with mainstream scientific understanding to increase our knowledge about the hydrology, geology, and ecology of the Amazon Basin.

Place-Based Water Names: Toward a Refined Classification for Wetlands

The Amazon Basin is one of the largest wetlands in the world (Fraser and Keddy, 2005). Wetlands are natural or artificial extensions of land saturated with water either permanently or seasonally, and they provide crucial environmental services but are being degraded rapidly; they need to be protected and used wisely (IUCN, 1971). Mainstream scientists (Junk et al., 2011) have only recently classified the wetlands of central and eastern

Amazonia from an ecological perspective. The classification by Junk et al. (2011) integrates folk names and concepts that met the researchers' ecological criteria. In western Amazonia, remote sensing might not be able to provide the resolution necessary to study the wetlands of the western basin, especially as access to certain areas of the basin is difficult due to political and natural constraints. Indigenous knowledge could provide us with the information we need to understand and classify these wetlands.

With further study, we should be able to elucidate the Uitoto taxonomy for water and wetlands in the western basin and use it to complement our current knowledge. Next, we present examples of overlapping wetlands categories: first those provided by Junk et al. (2011), followed by the native experts' categories.

(1) Wetlands with relatively stable water levels, and forested swamps in the rain-forest palm swamps and mixed forests: These areas remain waterlogged and could be flooded during the rainy season. During the dry season, they store water and gently release it to feed connected streams. They buffer surface runoff during heavy rainstorms. Organic matter accumulates but also decomposes.

Kɨnére (*Canangucho* palm swamp/*canangucha*l): Water that originates in flooded palms forests of *canangucho*, *Mauritia flexuosa* palm. The water flows very slowly and never dries up, but its area shrinks during the dry season. The Uitoto distinguish two types of water according to the hydrological cycles of high and low water levels. Water from low water occupies less volume and is referred to as small *canangucha*l water. It accumulates between the roots of the palms. It is grayish and smells like animal musk. The water tastes semi-acid due to the palm's biological processes, which determines its characteristics. Water from the high water season occupies a larger area and is different than the water in contact with the roots. This water is referred to as "long or large *canangucha*l water." Contrary to the small variety, the water appears clear or blue/green, and it has no odor and an earthy taste, which some people find more palatable than the smaller *canangucho* water. It is also safe to drink.

It is a cultural belief that water bodies have owners; the owners are the caretakers of the place and its beings. For example, the black boa is the owner of the *canangucha*l; its presence guarantees that the *canangucha*l will not dry. Like the boa, the *canangucho* palm is closely associated with water and acts as a protector. This culturally based assertion has not been tested by mainstream science, but it could indicate testable ecological interrelationships.

(2) Wetlands with oscillating water levels, subjected to predictable, long-lasting, monomodal flood pulses, low flood amplitudes, and hydromorphic edaphic savannas of low fertility: Areas with insufficient drainage can host interfluvial wetlands during rainy seasons. For example, strongly leached, low-fertility soils with an underlying hardpan of deposited minerals can be shallowly flooded. Depressions may be filled with fine-grained kaolinite. These places can host unique plant and animal communities. Other names for this kind of wetland in central and eastern Amazonia are *campina*, *bana*, *muri* scrub vegetation, *campirana* forest, and *varillales.* These wetlands are difficult to access, hindering their study.

Tapíre: These places are also known locally as *chuquiales*, composed of low, dense root-mat forests. Some of the *chuquiales* are white, like a white-sand beach (*koniyikɨ*). The soil is sometimes soft due to the *úterede noggora* (kaolinite). Roots and branches intertwine in these areas, which are not like a lake or well, but the soil is soft (*toórede*). The water comes from rain, and the *chuquial* can dry during summer. Some of the vines provide water too, but the water is bitter (*érɨji*) and sluggish. It smells like rotten leaves and is unsafe to drink. It contains parasites or small animals. The water almost does not flow. There are beasts, dangerous animals, and it is not a good place to visit (Londono, Makuritofe, this work).

As the examples demonstrate, native classifications encompass ecological associations that could help to inventory and differentiate wetlands in the northwestern part of the basin, providing a framework with which to manage or protect them.

Chemical Analysis of Some Uitoto Water (Jaɨnoi) Types

Quantitative and analytic methods from mainstream science can be applied in ethnogeology. Native researchers sampled different water types: *churuгapo*, *imáni*, *jíruebɨ*, *jɨ=dɨye*, and *kɨnére*, translated as spring (literally: flowing from a hole), main river, muddy water, black water, and palm swamp water (*Mauritia flexuosa* swamp; Table 1). Because the chemical distribution in streams has been used to differentiate water types in the Amazon (Gibbs, 1972; Sioli, 1984; Stallard and Edmond, 1983; Devol et al., 1995), we evaluated the ions present in the samples provided.

Rigorous water sampling for chemical analysis requires that samples are filtered and sterilized in situ and stored at 4 °C. This preserves elements in solution and hinders biological processes, such as microbial metabolism, that utilize elements. Our samples were stabilized in Bogota, after ~1–2 wk of collection. Therefore, water data for N, S, and P should not be considered, as these elements actively participate in biochemical cycles. Conversely, the abundance of major ions in natural waters overwhelms the fraction that participates in biological cycles, and it can be assumed that their concentration does not significantly change in the sample (conservative species). Major ions also stay in solution for longer times (up to 42 d) and are less sensitive to temperature effects (Jackson, 2000). Furthermore, the values we found for major ions correspond to results in the literature (Devol et al., 1995). Therefore, we based our analyses and conclusions on the conservative species (i.e., Na^+, K^+, Ca^{2+}, and Cl^-; Table 2).

The *imáni*, main river water, had the highest ion concentration. The water with the lowest ion concentration was the *jɨ=dɨye*, black water in Uitoto. The concentration of individual ions varied in the analyzed samples; in general, *jíruebɨ* was the saltiest (Na^+, Cl^-), while *imáni* was rich in Ca and Mg. As described by Sioli (1956), white water is dominated by the alkaline earths (Ca^{2+} and Mg^{2+}) and the CO_3^- anion, which contributes most of the negative charge in the water of the Amazon's main stem (Stallard and Edmond, 1983).

Imáni means big or main river; it relates to the suffix *namani* found in the Uitoto names for rivers with considerable discharge,

TABLE 2. ION CHROMATOGRAPHY DATA OF MAJOR IONS IN WATER SAMPLES

Sample	Na^+ (μM)	K^+ (μM)	Mg^{2+} (μM)	Ca^{2+} (μM)	Cl^- (μM)	NO^{3-} (μm)
Chururapo-1	41.4	5.6	1.1	5.3	32.9	14.5
Chururapo-2	39.7	6.1	1.4	5.0	34.4	67.8
Chururapo-3	42.2	5.9	0.8	4.5	35.8	64.2
Mean	41.1	5.9	1.1	4.9	34.4	48.8
S.D.	1.2	0.2	0.3	0.4	1.5	29.8
Imáni-1	46.4	42.1	20.4	63.4	45.5	19.3
Imáni-2	43.1	23.4	19.8	55.7	17.5	98.8
Imáni-3	40.7	19.9	19.7	56.2	10.3	10.0
Mean	43.4	28.4	20.0	58.4	24.4	42.7
S.D.	2.8	11.9	0.4	4.3	18.6	48.8
Jíruebi-1	42.4	8.0	1.1	3.3	55.5	9.9
Jíruebi-2	37.9	8.3	1.4	3.9	49.6	5.9
Jíruebi-3	63.3	9.3	0.8	3.1	63.1	6.4
Mean	47.9	8.5	1.1	3.4	56.0	7.4
S.D.	13.5	0.7	0.3	0.4	6.7	2.2
Ji¯diye-1	9.6	8.2	3.1	9.0	5.6	43.0
Ji¯diye-2	10.5	8.8	3.6	12.6	5.0	25.0
Ji¯diye-3	10.0	8.0	3.0	5.8	5.7	32.5
Mean	10.0	8.3	3.2	9.2	5.4	33.5
S.D.	0.4	0.4	0.3	3.4	0.4	9.0
Kinére-1	23.3	7.9	5.5	15.9	14.4	3.4
Kinére-2	22.7	8.0	5.5	15.7	14.3	2.6
Kinére-3	22.78	7.6	5.4	15.9	13.5	2.2
Mean	22.9	7.8	5.5	15.9	14.1	2.7
S.D.	0.3	0.2	0.1	0.1	0.4	0.6

Note: NO^{3-} data should be interpreted carefully due to sampling limitations. NH_4^+, F^-, NO^{2-}, Br^-, SO_4^{2-}, and PO_4^{3-} are below detection limits. See text for details. *Chururapo*—spring, *Imáni*—main river, *Jíruebi*—muddy water, *Ji¯diye*—black water, and *Kinére*—*Mauritia flexuosa* palm swamp.

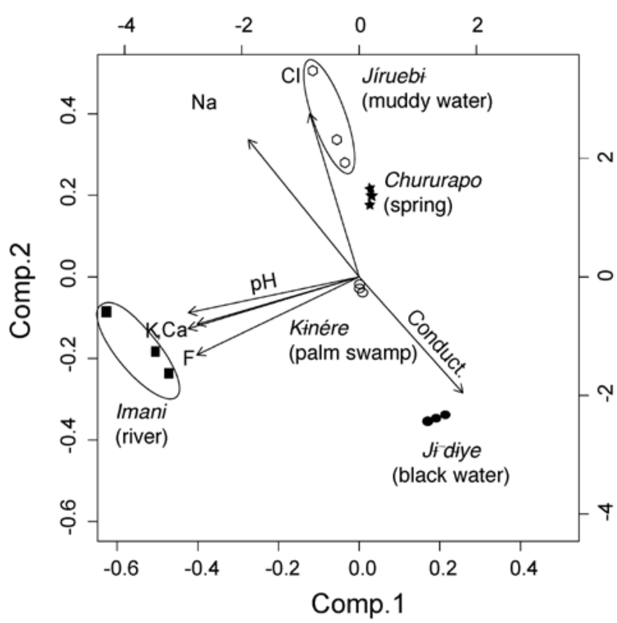

Figure 6. Principal component analysis of 15 water samples. PC1 explains 63% of the data variation and is related to water origin. PC2 explains 31% of data variation and seems to relate to the flow rate of the water.

such as the Putumayo (*Koniyɨnamani*), Caqueta (*Uigonamani*), and Amazonas (*Moníyanamani*), with Andean origin. Thus, at least preliminary, white-water rivers seem to relate to the Uitoto categories *imáni*.

Traditional ways of classifying resources are based on their uses in medicine. Medical uses of Amazon waters are yet to be studied in ethnohydrology. Mainstream science has characterized black-water rivers by their organic, humid acid content. We did not measure organics in our research, but the Uitoto use the category: black water. We speculate that the mainstream and native categories overlap. However, in traditional medicine, the Uitoto know of different types of medicinal black water, for example, one to treat chills, and another one to treat allergies. It is possible that the documented astringent properties of the tannins present in the water contribute to its healing effects. Yet, more work is needed to learn from the elders about these advanced, and specialized topics in native science.

Jíruebɨ contains a red mud with ascribed healing properties. Antibacterial clays have been identified in the study area (Londono and Williams, 2015), but the red mud and the water associated with it have yet to be studied.

These results show that while certain categories of water, and its properties, can be compared between Uitoto and mainstream sciences, others are unknown. In particular, the medicinal uses of water remain limited to a cultural practice. Deeper understanding of water properties could have implications for health and would provide a basis on which to propose alternative ways to value and use the water resource.

Principal Component Analysis (PCA)

To further analyze the water chemistry, we used PCA, a statistical technique used to identify the underlying structure of data. In our analysis, we used the concentrations of the major ions Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^-. The PCA showed that each of the native water types is distinct from every other, confirming a chemical basis for the indigenous characterizations (Fig. 6).

In Figure 6, the components PC1 and PC2 explain 63% and 31% of the variation in the data, respectively. However, samples that plot close to the origin of the vectors (e.g., *kɨnére*) are not satisfactorily explained by these components, presumably because major ion content is insufficient to characterize the water. According to the Uitoto, *kɨnére* water cannot be separated from the *canangucho* palm; it is so closely associated that the water sample was sent with a small *canangucho* seedling (despite the instructions to avoid sediment or any other particulates in the bottles). Because we did not collect organic data, which seem to be key in this case, *kɨnére* is excluded from this discussion. To the left of the *x* axis (PC1), the *imáni*, main river water, exemplifies waters that drain the Andes (white water). To the far right, the *jɨ¯dɨye*, black water, drains local lowland materials, and its color relates to organic input. Thus, the PC1 axis would seem to correspond to mainstream scientific classifications of water color. However, *jíruebɨ* and *chururapo* are not from runoff. They plot close to one another and midway between the white and black waters. Their sources are local deposits such as the Caquetá River deposits and the Miocene Pebas Formation (Fig. 3). The red mud associated with *jíruebɨ* is likely derived from soils of the Ali-Acrisol group, developed in Andean-origin deposits (Lips and Duivenvoorden, 1996). However, the intense weathering environment has imprinted its geochemical signature on the Andean sediments, increasing the kaolinite, oxide, and hydroxide contents. Thus, PC1 seems to represent the chemical print of materials in contact with the water: Andean to the far left; local, weathered materials from the Andes in the center; and local, humic and organic materials in the far right; this component explains 60% of the data.

We hypothesize that the PC2 axis in Figure 6 represents whether the water is running or environmentally contained. This would explain 30% of sample variation. The water from runoff (i.e., *imáni*: river, and *jɨ¯diye*: creek) plots at the bottom. The *kɨnére*, which slowly flows in the floor of the flooded forest, plots in the middle. The flow in the palm swamp is more tortuous, as it moves through a rough surface with roots, woods, and flooded-forest vegetation. At the top, *chururapo* and *jɨruebɨ* are sourced by springs. *Jɨruebɨ* water is found in red clayey soils that give the water its color. However, the swampy area is fed by a spring, not by precipitation, according to the native specialists. Therefore, it is possible that both *chururapo* and *jɨruebɨ* represent groundwater flow, or water that was environmentally contained. As we collect more data, we will be able to test our hypothesis.

These chemical and statistical analyses demonstrate that the water types classified by the Uitoto are indeed different from one another, and they show how the Uitoto categories can be evaluated using mainstream scientific methods.

IMPLICATIONS OF THE STUDY

The oral tradition is a medium used to explain, conserve, and convey cultural patterns, from codes of behavior to the systematic nomenclature that supports specific knowledge. Some oral stories are reservoirs of information that could be explored for environmental and geological data. Further study could provide a refined classification of wetlands for the Colombian Amazon, which is necessary to enable Colombia to comply with the Ramsar convention on wetlands (IUCN, 1971; Ramsar Convention Secretariat, 2013). Findings from our study can be used to create cross-cultural educational materials for use in both native and mainstream schools.

CONCLUSION

We performed an ethnogeology case study with native coresearchers on Uitoto land. We compared the native knowledge of the natural history of the Amazon and the kinds, characteristics, and uses of its water with data obtained by mainstream geoscientists, and we found correlations between the two. We also found that in many cases, native knowledge was more complete and nuanced than that of mainstream science. This implies that native knowledge that accrues in a given study area can enhance mainstream scientific understanding of that area. Our study demonstrates that ethnogeology can be used to conduct basic and applied research at the same time, producing both intellectual and practical outcomes.

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