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Research Paper

Geospatial patterns in traditional knowledge serve in assessing intellectual property rights and benefit-sharing in northwest South America

Rodrigo Cámara-Leret [a,c], Narel Paniagua-Zambrana [b], Jens-Christian Svenning [c], Henrik Balslev [c], Manuel J. Macía [a,*]

[a] Departamento de Biología, Área de Botánica, Universidad Autónoma de Madrid, Calle Darwin 2, ES-28049 Madrid, Spain
[b] Herbario Nacional de Bolivia, Universidad Mayor de San Andrés, Campus Universitario, Cota Cota calle 27, Casilla-Correo Central, 10077 La Paz, Bolivia
[c] Ecoinformatics & Biodiversity, Department of Bioscience, Aarhus University, Ny Munkegade 114, Aarhus C, DK-8000 Aarhus, Denmark

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A B S T R A C T

Ethnopharmacological relevance: Without an understanding of the geography of traditional knowledge, implementing the Nagoya Protocol and national or regional strategies for benefit-sharing with local and indigenous communities will be difficult. We evaluate how much traditional knowledge about medicinal palm (Arecaceae) uses is unique and how much is shared across (i) four countries (Colombia, Ecuador, Peru, Bolivia), (ii) two cultural groups (Amerindian and non-Amerindian), (iii) 52 Amerindian tribes, (iv) six non-Amerindian groups, (v) 41 communities, and (vi) individuals in the 41 communities.
Materials and methods: We first sampled traditional knowledge about palms from 255 references and then carried out 2201 field interviews using a standard protocol. Using the combined data set, we quantified the number of "singletons" that were unique to one of the analyzed scales. For the 41 communities, we evaluated how many uses were cited by $<10\%$ and by $\geq 50\%$ of informants. We performed a Kruskal–Wallis test to evaluate whether the number of unshared uses (cited by $<10\%$) differed significantly in relation to the informants' gender and degree of expertise, and performed a two-way ANOVA to test for differences in the number of unshared and shared uses accounted for by the five birth cohorts.
Results: We found that most knowledge was not shared among countries, cultural groups, tribes, communities, or even individuals within them. Still, a minor knowledge component was widely shared, even across countries. General informants cited a significantly higher number of unshared uses than experts, whereas no significant differences were found in the number of unshared uses cited by men and women or by different age groups.
Conclusion: Our region-wide analysis highlights the geospatial complexity in traditional knowledge patterns, underscoring the need for improved geographic insight into the ownership of traditional knowledge in areas where biocultural diversity is high. This high geographic complexity needs consideration when designing property right protocols, and calls for countrywide compilation efforts as much localized knowledge remains unrecorded.

1. Introduction

Traditional knowledge (TK) about biodiversity can accelerate drug discovery, and as a result, it has contributed to bioprospecting efforts and consequently triggered intense debates over intellectual property rights (Posey, 1990; Jayaraman, 1997; Anonymous, 1998; Laird, 2002; Schiermeier, 2002). The Convention on Biological Diversity (CBD) aims to regulate this important, but problematic area. Building on the CBD, the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* was adopted in 2010 to support the implementation of the CBD (SCBD, 2011). The Nagoya Protocol addresses biopiracy and misappropriation of genetic resources. It emphasizes prior informed consent and mutually agreed upon terms for benefit-sharing with the governments and indigenous peoples and local communities involved in return for access to genetic resources. The Nagoya Protocol significantly advances indigenous and local community rights by (i) affirming that the rights of indigenous-local communities under the CBD are not dependent on the discretion of the state, (ii) advocating compliance to customary laws and

* Correspondence to: Departamento de Biología, Área de Botánica Edificio de Ciencias Biológicas Universidad Autónoma de Madrid, Campus de Cantoblanco Calle Darwin, 228049 Madrid, Spain. Tel.: +34 914978107; fax: +34 914 978344.
E-mail address: manuel.macia@uam.es (M.J. Macía).

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community protocols when accessing community resources and knowledge, (iii) securing the rights of indigenous-local communities over their genetic resources, (iv) making clear reference to the importance of the United Nations Declaration on the Rights of indigenous peoples, and (v) making the Nagoya Protocol the main instrument for the enforcement of CBD-related rights over genetic resources and associated TK (Bavikatte and Robinson, 2011). In addition to the Nagoya Protocol, concern over TK and intellectual property rights has led the World Intellectual Property Organization to establish the Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore. Currently, negotiations are underway for the development of an international legal instrument to effectively protect traditional expressions of culture and TK and to address the intellectual property aspects of access to and benefit-sharing of genetic resources (WIPO, 2014).

Despite these legal advances, a crucial, but overlooked issue is the degree to which TK is shared geographically among nations and major cultural groups or, alternatively, unique to specific local communities or even individuals. Many individual efforts directed at specific ethnic groups have advanced our understanding of TK over more than a century (Schultes and Raffauf, 1990; De la Torre et al., 2008). However, ethnobotanical knowledge is still vastly underdocumented (Cámara-Leret et al., 2014a) and cross-cultural studies are limited to few ethnic groups and small geographic regions. Still, these studies have provided evidence for the existence of both localized and widespread TK on medicinal use. Notably, they show that the same medicinal plants may be used differently by adjacent communities (Junsongduang et al., 2014), that adjacent communities sometimes select different plant species for the same medicinal use (Shepard, 2004), that communities within a single ethnic group may exhibit both idiosyncratic and widespread ethnobotanical knowledge (Srithi et al., 2012), and that patterns of knowledge sharing may vary geographically (Vandebroek, 2010). Nevertheless, the multi-scale, inter-ethnic geographic comparisons necessary to elucidate the highly important and policy-relevant spatial structure of TK sharing patterns are missing.

An accurate understanding of the geography of TK is essential for compliance with Article 10 of the Nagoya Protocol which calls for “a global multilateral benefit-sharing mechanism to address the fair and equitable sharing of benefits derived from the utilization of genetic resources and TK associated with genetic resources that occur in transboundary situations or for which it is not possible to grant or obtain prior informed consent” (SCBD, 2011). Rigorously designed research that compares the TK held by multiple cultures, communities, and individuals is needed to shed light on these issues. “Big data” approaches that encompass large spatial scales and include different cultural groups are essential.

In this study, our primary objective is to investigate the geographic distribution of TK across an area of exceptional biocultural diversity, the northern South American tropics, and to relate our findings to the benefit-sharing provisions outlined in the Nagoya Protocol. Focusing on the South American tropics is particularly relevant: this region supports the richest flora on Earth and has high bioprospecting potential (Schultes and Raffauf, 1990); the inhabitants of this region hold high levels of TK of genetic resources (Schultes and Raffauf, 1990; Barfod and Kvist, 1996; De la Torre et al., 2008; Macía et al., 2011; Cámara-Leret et al., 2014a); and there is a high probability that TK about these genetic resources could be exchanged across country borders due to the widespread use of Spanish and indigenous languages in the region. Specifically, we evaluate how much TK is unique to and how much is shared across (i) four countries (Colombia, Ecuador, Peru, Bolivia), (ii) two cultural groups (Amerindian and non-Amerindian), (iii) 52 Amerindian tribes, (iv) six non-Amerindian groups, and (v) 41 communities. We use the palm family (Arecaceae) as a model group and focus on its medicinal uses because ethnobotanical research in tropical South America has long focused on these plants due to their extraordinary importance to indigenous and other rural communities in the region (Balick, 1984; Balick and Beck, 1990; Macía et al., 2011) and because the medicinal potential of palms has been increasingly recognized over the last few decades (Plotkin and Balick, 1984; Sosnowska and Balslev, 2009; Zhu et al., 2011; Macía et al., 2011). In addition, their frequent use and relatively easy identification make cross-cultural comparisons possible. After first determining the medicinal uses of palms that are unique at different scales, from countries to communities, we then assess the need for national strategies to protect unique TK. Furthermore, by separating out countries, cultural groups, palm species and medicinal uses with the greatest degree of sharing, we provide uniquely detailed insights relevant to current regional strategies directed at developing a multilateral benefit-sharing mechanism. This is, to our knowledge, the first attempt to quantify the multi-scale geospatial patterns of TK about a keystone plant family in South America or any other large region of the world.

2. Methods

2.1. Study area and cultural groups

The research was conducted in the western Amazon basin and in the biodiversity hotspots of the tropical Andes and the Chocó. This region ranks second globally in palm diversity (Dransfield et al., 2008) and is populated by a multitude of indigenous Amerindian and non-Amerindian groups (Lewis et al., 2013) whose livelihoods depend on forest-based products. Within this region, our analyses were conducted at five nested spatial scales: (i) countries, including Colombia, Ecuador, Peru, and Bolivia; (ii) a broad category encompassing Amerindian and non-Amerindian peoples; (iii) Amerindian tribes ($n=52$); (iv) Non-Amerindian groups ($n=6$), which include (a) mestizos, people of mixed origin who are of European–Amerindian descent, (b) Afro-Americans, people of African ancestry; and (v) communities with ≥ 10 informants of the same ethnicity ($n=41$).

2.2. Data collection

We collected information about the medicinal uses of palms from two sources: (i) interviews ($n=2201$) made over 18 months of fieldwork (May 2010 to December 2011), from which a total of 1392 informants reported on medicinal uses, and (ii) the published ethnobotanical literature, including the 255 references reviewed in Macía et al. (2011) as well as recent works published from 2010 to 2013. Before starting fieldwork in northwestern South America, we developed a standard protocol for gathering ethnobotanical data (Paniagua-Zambrana et al., 2010; Cámara-Leret et al., 2012). Communities were selected on the basis of having a uniform ethnic composition, different degrees of accessibility to markets, and access to mature forests for harvesting palm resources. Ethnobotanical data were collected from two types of informants: experts, of whom we interviewed 1–7 in each community (total $n=171$), and generalists, of whom we interviewed 1–85 in each community (total $n=2030$). The selection of the experts was done by consensus during a meeting of community members. In communities that were too large to gather all members, such as Andean sites with populations exceeding 1000 inhabitants, experts were recruited by asking several general informants to recommend their most knowledgeable peers. Experts were mostly men (78%) and older than 40 years (70%). Walks in the field with each of them were taken to document the uses of palms and to compile a list of the vernacular names for as many palm species as possible. Once experts were interviewed, we used the list of compiled vernacular names as the basis for interviews with the general informants. We selected general informants in each community (or group of communities belonging to one ethnic group when there were fewer than 87 informants in one community) in a stratified manner to achieve a sample representative of gender (women, $n=1107$; men, $n=1094$) and age class (18–30 years, 28%; 31–40 years, 23%; 41–50 years, 20%; 51–60 years, 13%; >60 years, 16%). Interviews were conducted in Spanish or in the local language with the help of a local interpreter when needed. Palm species were identified in the field, and specimens were collected when our field identifications needed confirmation. Voucher specimens were deposited in the herbaria of AAU, AMAZ, CHOCO, COL, LPB, QCA and USM (acronyms according to Thiers (2014). We followed the World Checklist of Palms to unify the nomenclature (Govaerts and Dransfield, 2005).

2.3. Data analyses

To assess how much TK was shared or unique to one of the study groups, we first classified medicinal use reports from the literature and fieldwork into 21 subcategories following the Economic Botany Data Collection Standard (Cook, 1995) with some modifications proposed by Macía et al. (2011). We defined each "medicinal palm use" as the use of a palm part from a given species associated with a medicinal subcategory. All literature reports that did not mention the palm part used, or that only referred to a species as medicinal but did not specify the medicinal use, were omitted; these medicinal uses are represented in Macía et al. (2011) by the "Not specified" medicinal subcategory. For simplicity, we term medicinal uses that were unique to one of the analyzed scales as "singletons". Using the combined dataset of the literature and fieldwork, we evaluated the number of singletons at the different scales.

For the community-scale analyses, only those communities with ≥ 10 informants of the same ethnic group were considered. In total, 41 communities inhabited by Amerindians ($n=28$) and non-Amerindians ($n=13$) met this criterion. For each community we first evaluated how many uses were cited by $<10\%$ and by $\geq 50\%$ of informants. For simplicity, we call medicinal uses cited by $<10\%$ of informants "unshared" uses and those reported by $\geq 50\%$ of interviewees "shared" uses. We then looked for correlations between the number of unshared and shared uses and the total number of uses cited in the communities. We performed a Kruskal–Wallis test to evaluate whether the number of unshared uses differed significantly in relation to the informants' gender and degree of expertise. To test for differences in the number of unshared and shared uses accounted for by the five birth cohorts, we performed a two-way ANOVA. Finally, we calculated how many unshared and shared uses were distributed among the different palm species and medicinal subcategories across all communities. All analyses were performed in R 3.0.1 (R Development Core Team, 2014).

2.4. Ethics statement

Approval for the fieldwork component of this study was granted by the Committee for Ethical Research of the Autonomous University of Madrid (#48-922; PI Manuel J. Macía). We conducted our field research in association with the following local institutions: Universidad Nacional de Colombia; Pontificia Universidad Cátolica del Ecuador; Universidad Nacional Mayor de San Marcos (Peru); and Universidad Mayor de San Andrés (Bolivia). Before initiating in situ data collection, we obtained oral informed consent at the village level and then from the individual prior to each interview out of respect for the fact that some interviewees lacked reading or writing skills. The ethics committee of the Universidad Autónoma de Madrid approved this procedure. The methods were carried out in accordance with the approved guidelines. The consent to participate was recorded by writing the date and name of the informant on the interview questionnaire. Informants were made aware of their right to discontinue the interviews at any time and that all of the information provided would be anonymized.

Palm collection permits were obtained through the following authorities: Instituto Amazónico de Investigaciones Científicas Sinchi (Colombia); the Ministry of Environment (Ecuador); the Instituto Nacional de Recursos Naturales (Peru); and the Dirección General de Biodiversidad y Areas Protegidas (Bolivia). The field studies did not involve endangered or protected species.

3. Results

3.1. TK among countries

Together, our combined interviews and data derived from the literature yielded 503 different medicinal uses for 86 palm species. Most TK about palms was not shared at any scale (i.e., countries, cultural groups, Amerindian tribes, non-Amerindian groups, communities, and individuals) (Fig. 1). A mean of $85\pm9\%$ of all uses within each of the 19 medicinal subcategories were country singletons (Table S1). Colombia had the greatest number of medicinal use singletons followed by Bolivia. The medicinal subcategories of *Digestive system* followed by *Respiratory system* accounted for the greatest number of country singletons (Table S1).

The sharing of TK across country borders occurred in a non-negligible minority of cases, i.e., for 82 uses (16% of all uses) and 21 species. The species for which TK was most commonly shared across countries were *Oenocarpus bataua* (17 uses) and *Euterpe precatoria* (13). Fifty-three of all transboundary uses, representing 10% of the total number of country uses, were shared between just two nations, mostly between Peru and Bolivia (Table S2). In contrast, transboundary sharing of TK between four nations was limited to 11 uses (2% of all country uses) and to four palm species: *Oenocarpus bataua*, *Euterpe precatoria*, and the cultivated *Bactris gasipaes* and *Cocos nucifera*.

3.2. TK among Amerindians

Over 80% of the medicinal uses of palms were not shared between Amerindian and non-Amerindian peoples as a whole (Fig. 1b). Most of these unshared uses were unique to Amerindians (83%), and most were even unique to a single Amerindian tribe (Fig. 1c). The three tribes with the highest number of singletons were the Tikuna in Colombia, the Leco in Bolivia, and the Huaorani in Ecuador (Table S3). Nearly 30% of Amerindian singletons were concentrated in the medicinal subcategories of *Digestive system* (14%), *Skin and subcutaneous tissue* (10%), and *Respiratory system* (10%). All but one of the Amerindian tribes shared some medicinal uses with at least one other tribe (Table S4). The mean number of Amerindian tribes that shared at least one use with another tribe was 22 ± 12 ($N=52$). Sharing of TK with other tribes was greatest in the Tikuna and the Macuna of Colombia and the Quichua of Bolivia, each of which shared uses with at least 40 other tribes. Three widespread and common wild species, *Oenocarpus bataua*, *Euterpe precatoria* and *Attalea phalerata*, accounted for ~40% of the shared uses between tribes. Two medicinal subcategories, *Infections and infestations* and *Skin and subcutaneous tissue*, accounted for ~30% of all shared uses between tribes.

3.3. TK among non-Amerindians

About 90% of the 167 medicinal uses cited by non-Amerindians were singletons restricted to one of the six groups (Fig. 1d). Most singletons were confined to Bolivian mestizos (30% of all non-Amerindian singletons) and to Afro-Americans in Colombia (17%). On

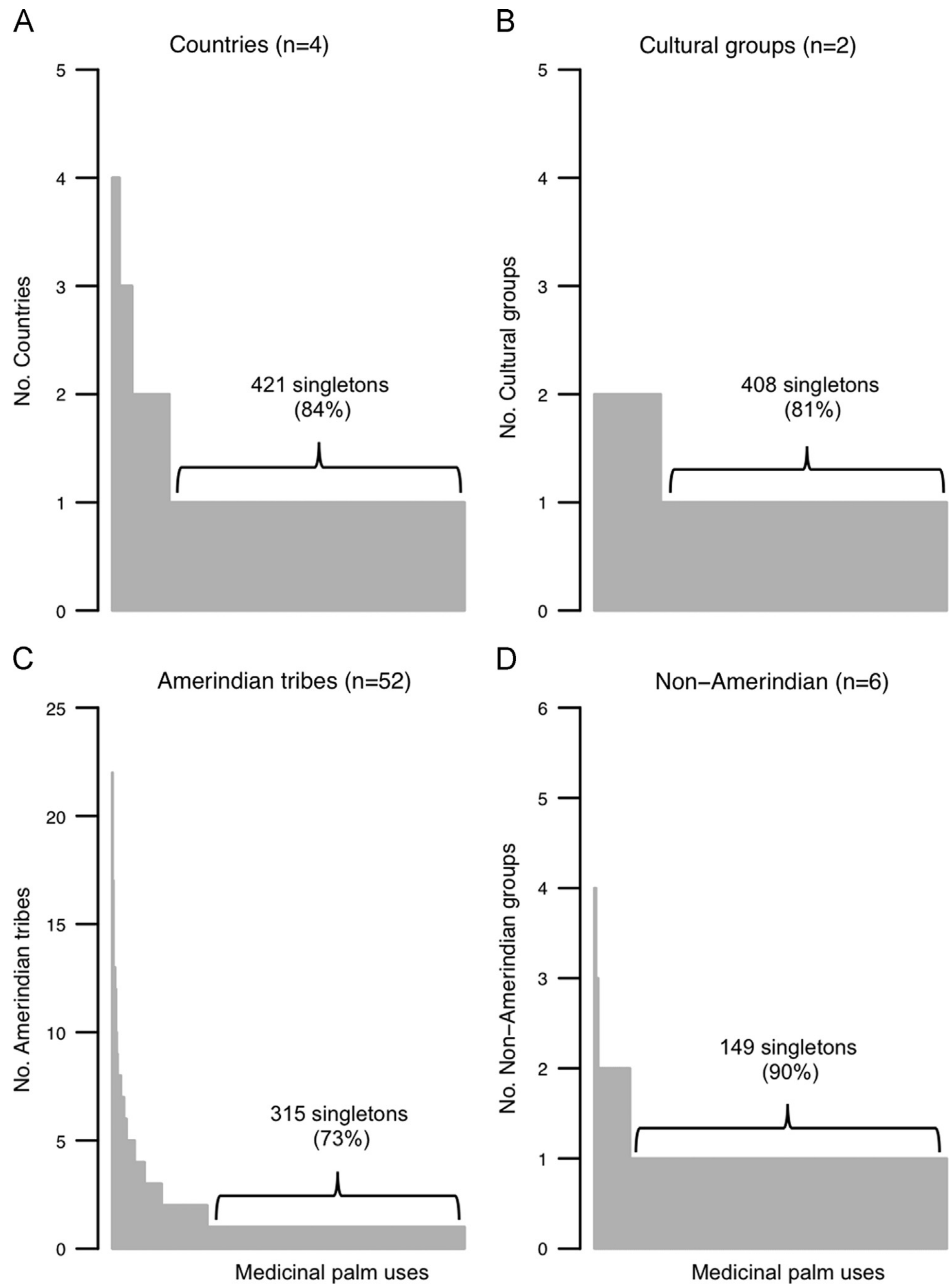

Fig. 1. Frequency of shared medicinal uses and singletons among (A) countries, (B) cultural groups, (C) Amerindian tribes, and (D) non-Amerindian groups.

the other hand, nearly 80% of all of the uses shared between non-Amerindian groups were between Bolivian and Peruvian mestizos (Table S5) and were limited to seven palm species. Long-distance sharing of TK was found between many non-Amerindian groups, such as between Bolivian and Ecuadorian mestizos and between Afro-American Colombians and Peruvian mestizos. In ~25% of the cases, long-distance sharing of TK was associated with the use of the cultivated *Cocos nucifera* and in ~30% of the cases with the use of *Oenocarpus bataua*, one of the most widespread and common wild palm species in the region. All cases of TK sharing by more than two non-Amerindian groups were linked to *Cocos nucifera*.

3.4. TK among communities

Altogether, our fieldwork in the 41 communities with >10 informants of the same ethnicity yielded a total of 262 medicinal uses for 55 species. In contrast to the results at other scales, more uses were shared between communities (54%) than were community singletons (Fig. 2). Surprisingly, most medicinal uses were not shared between communities of the same ethnicity (Table S6).

3.5. Differences between TK holders

Traditional knowledge within the 41 communities was unevenly distributed and consisted of mostly "unshared" uses cited by $<10\%$ of the informants (Fig. 3). The number of unshared uses was positively correlated with the total number of medicinal uses cited in the same community ($p<0.001$) (Fig. S1). Thus, the amount of idiosyncratic knowledge increased with increasing levels of knowledge in a community. To further understand how unshared uses were distributed among TK holders, we compared how many unshared uses were cited by general and expert informants, by men and women, and by five age

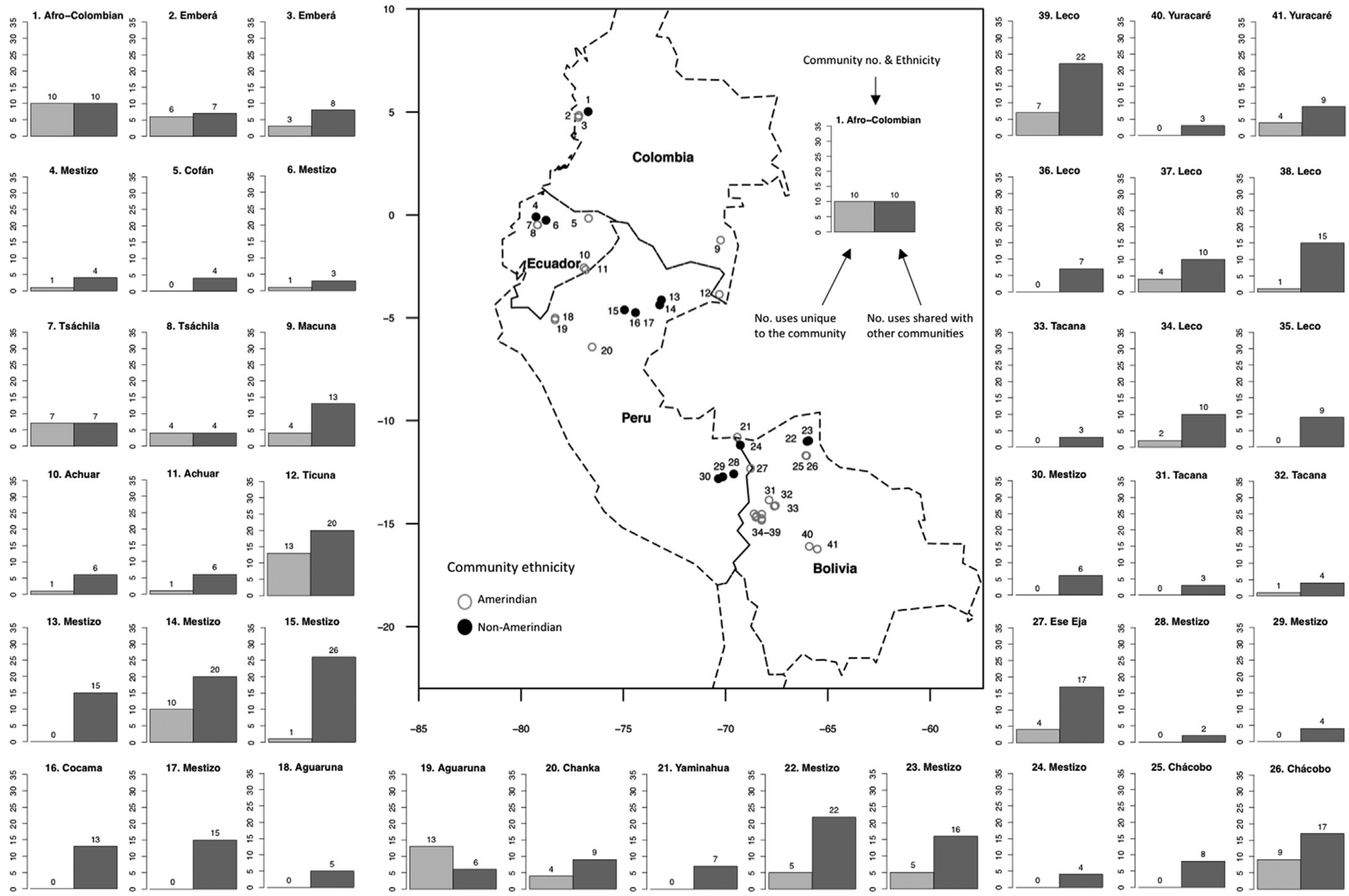

Fig. 2. Distribution of palm medicinal knowledge in 41 communities from northwestern South America, showing the number of medicinal uses unique to the community (light gray bars) and the number of medicinal uses shared with other communities (dark gray bars) for each community with ≥ 10 informants. Numbers on the map and the bar plots refer to the 41 communities surveyed along a north to south latitudinal gradient. Names on the bar plots refer to the ethnicity of the community.

groups in each community. Surprisingly, general informants cited a significantly higher number of unshared uses than experts (Kruskal–Wallis test: $H=14.51$, $p<0.001$), whereas no significant differences were found in the number of unshared uses cited by men and women or by different age groups. The highest number of unshared uses was found for the subcategories of *Skin and subcutaneous tissue*, *Digestive system*, and *Blood and Cardio-vascular system* (Fig. S2a). Of all the palm species, *Bactris gasipaes* had the greatest number of associated unshared uses and, together with *Euterpe precatoria*, *Attalea phalerata*, *Cocos nucifera* and *Oenocarpus bataua*, accounted for $>33\%$ of all unshared uses (Fig. S3a).

On the other hand, we found that in 25 of the 41 study communities at least one use was shared by $\geq 50\%$ of informants (Fig. 3). These widely-shared uses concerned nine species and 19 different medicinal uses (Figs. S2b and S3b). Interestingly, 95% of the uses that were widely shared within a community were also reported in other communities.

4. Discussion

It is well established that TK can accelerate successful bioprospecting (Fabricant and Farnsworth, 2001). The Nagoya Protocol, one of the main mechanisms to protect TK, is based on the idea that individual countries possess unique biodiversity and related TK that may prove to be commercially valuable (Oldham et al., 2013). However, little is known about the geographic distribution of TK and how well this matches current laws and policies that seek to protect TK and fairly compensate custodians when their knowledge is accessed. Our investigation addresses this neglected area and provides the first assessment of how much TK about medicinal palms is shared or unique across scales from individuals within a community to countries in tropical South America.

Our results indicate that TK of the medicinal uses of palms was mostly not shared at any of the geographical and biocultural scales: countries, cultural groups, Amerindian tribes, non-Amerindian groups, communities, and individuals. The high levels of unique TK at the country level support the development of national legislation to protect the TK that is unique to a nation. Some South American nations have enacted *sui generis* laws to protect TK, such as Peruvian law #27811 that establishes special protection for the collective knowledge of indigenous groups (de la Cruz et al., 2005). Nevertheless, implementation of the law is problematic because it (i) only considers Amerindian groups to be TK custodians and dismisses the wealth of TK held by non-Amerindians, (ii) designates unrealistic fee structures that are unattractive to pharmaceutical companies, and (iii) requires assembling the collective TK of Peru, a task that has yet to be undertaken (Elvin-Lewis, 2006). Furthermore, an operational mechanism for acquiring revenue and auditing companies, which is necessary for the distribution of benefits to the proposed Indigenous Fund, has not been implemented (Ministerio de Ambiente Perú, 2013). These problems need to be solved in Peru and addressed by other nations as part of the process of developing *sui generis* laws to protect TK.

In Ecuador, TK databases have been devised that aim to protect TK by transforming ethnobotanical knowledge into trade secrets (i.e., the Ecuador Knowledge Cartel) (Vogel, 2000). This method,

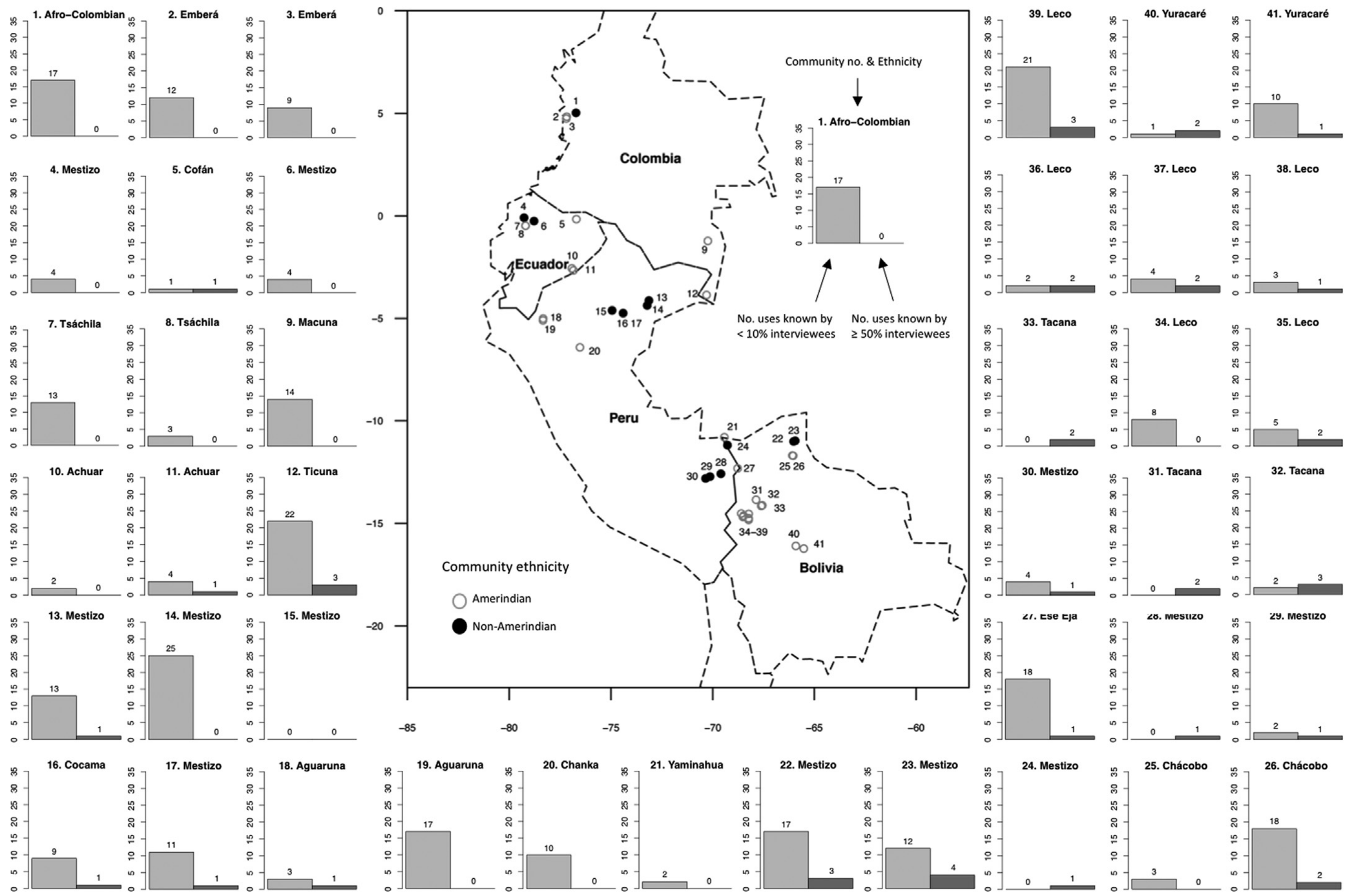

Fig. 3. Distribution of palm medicinal knowledge in 41 communities of northwestern South America showing the number of medicinal uses known by $< 10\%$ interviewees (light gray bars) and the number of medicinal uses known by $\geq 50\%$ of interviewees (dark gray bars) for each community with ≥ 10 informants. Numbers on the map and the bar plots refer to the 41 communities surveyed along a north to south latitudinal gradient. Names on the bar plots refer to the ethnicity of the village.

which was pioneered in India, provides evidence of prior knowledge to patent examiners and can limit the granting of patents and the commercialization of efforts based on TK (TKDL, 2014). After forcing the US Patent and Trademark Office to revoke a patent on turmeric, India's Council for Scientific and Industrial Research launched the Traditional Knowledge Digital Library in 2001 to prevent patents for non-original innovations (Jayaraman, 1997; TKDL, 2014). Traditional knowledge databases, however, have yet to be launched in most South American nations.

Our finding that the same TK associated with genetic resources has been shared by different countries calls for greater transboundary cooperation as outlined in Article 11 of the Nagoya Protocol. Article 11 states that "those Parties shall endeavour to cooperate, as appropriate, with the involvement of indigenous and local communities concerned, where applicable, with a view to implementing this Protocol" (SCBD, 2011). As mentioned previously, TK databases for use by patent examiners are mostly nonexistent in South American countries, are not standardized (Elvin-Lewis, 2006), and are country-specific. Redesigning current databases or establishing an international database may be necessary so that nations can identify these transboundary sharing situations. In South America, an important issue is that many Amerindian tribes straddle frontiers; at least 50 Amerindian tribes are frontier groups in South American countries (Lewis et al., 2013). Thus, it is plausible that the TK linked to members of one tribe will exist in all countries that are home to this tribe due to intra-cultural transmission. While there is some evidence of within-tribal TK sharing between multiple communities (Reyes-García et al., 2003), our analyses indicate that generalizations need to be made with caution since sharing patterns may differ from tribe to tribe (Table S6). "Big data" approaches, similar to that of Reyes-García et al. (2003), based on information queried from several hundred informants of a tribe will be invaluable for the further elucidation of the geographic distribution of TK in these frontier Amerindian tribes.

Most of the species for which TK is widely shared (e.g., *Oenocarpus bataua*, *Euterpe precatoria*, *Attalea phalerata*) are also the most useful (Macía et al., 2011; Cámara-Leret et al., 2014a), widespread, common, and therefore widely available (Ruokolainen and Vormisto, 2000; Macía and Svenning, 2005; ter Steege et al., 2013), and they are greatly appreciated by locals in the Amazon, Andes and Chocó ecoregions for the ecosystem services they deliver (Macía et al., 2011; Cámara-Leret et al., 2014b). Given that the bulk of drug discovery and patent activity are concentrated around a small number of well-known and cosmopolitan species (Oldham et al., 2013), the palms identified as showing high continental consensus in this study represent promising bioprospecting leads and will likely play a role in future transboundary agreements. Our finding that ~30% of TK shared by Amerindians was within two subcategories of use (i.e., *Infections and infestations* and *Skin and subcutaneous tissue*) also reveals that shared knowledge is non-randomly distributed in terms of its application (Macía et al., 2011).

An interesting finding from our analysis was the high number of singletons associated not just with Amerindians, but also with non-Amerindians. Most likely, the number of Amerindian tribe- and non-Amerindian group-restricted singletons is an underestimate because $> 50\%$ of the Amerindian tribes have yet to be studied, and there are still very few studies of the non-Amerindian groups in the region (Macía et al., 2011). Nevertheless, our results indicate that achieving a better understanding of the TK of the South American flora requires working with multiple cultures and not just indigenous groups (Phillips and Gentry, 1993).

In some cases, the source of TK might not be possible to ascertain. This is especially the case for the cultivated species *Bactris gasipaes* and *Cocos nucifera* for which we found an overlap of TK between distant cultural groups. For example, we found a higher frequency of long-distance sharing of TK among non-Amerindian groups associated with the widely-cultivated *Cocos nucifera*, a species that is prominent on the US Food and Drug Administration's list of approved nature-derived drugs (Zhu et al., 2011). How the Nagoya Protocol and national strategies will deal with these exceptional cases of native domesticated species for which there is transboundary sharing of TK remains to be clarified.

Our community analyses provide insights into the structure of TK and more specifically, to the question posed by Davis and Ruddle, (2010): How widely must knowledge be shared by community members before it can be regarded as TK? Even when we considered statements held by $>10\%$ of informants to be consensus, a very loose criterion, most medicinal knowledge was idiosyncratic or in the possession of only a few villagers. Thus, our community-level findings indicate that definitions of TK that require “sharing among villagers” to be a prerequisite are not congruent with the individualized nature of medicinal knowledge. Rather, TK of palms encompasses the sum of the different uses by the villagers, which are not necessarily shared. For example, our finding that none of the medicinal uses were shared by $>50\%$ of Emberá individuals (Fig. 3, communities 2 and 3) is consistent with studies from Panama, where the TK of Emberá women was not shared outside of the extended family for fear of poisoning others in the community (Potvin and Barrios, 2004).

Other important insights from our findings relate to the structure of TK and benefit-sharing policies. First, because most of the idiosyncratic knowledge was reported by general informants, but there were no differences between men and women, the notion that medicinal knowledge is restricted to certain social groups, such as community-selected experts or men (Reyes-García et al., 2007; Vandebroek, 2010), does not apply in this case. However, this finding cannot necessarily be generalized to other plant families, because palms have a comparatively greater salience and are easier to recognize by local people (Byg and Balslev, 2004; Byg et al., 2006). Second, we discard the idea that many of the low-frequency responses were from so-called charlatans because almost two-thirds of these low-frequency reported uses also occurred in other communities. Third, given the need for statistical significance in quantitative ethnobotanical studies, scholars will often exclude singletons from their analyses. This omission might lead to biased interpretations of TK because, as we have demonstrated, single-reports represent a considerable fraction of the medicinal knowledge in a village. The act of discarding single reports leaves little room for understanding how individual experiences may create shared knowledge systems (Srithi et al., 2012). The individual's role in the group should not be underestimated (Lewis and Ramani, 2007).

It is important to emphasize that the narrow geographical distribution and low density of many tropical rainforest species underlie the observed TK localization patterns. Accordingly, the observed patterns should not be generalized to other regions, especially temperate areas with less diverse floras. That said, we hypothesize that a strong localization of TK would also have been evident had we performed our analyses on other plant families or on other tropical regions of high biocultural diversity. Take the Amazon for example. Of its $\sim$16,000 tree species, 11,000 species are considered rare with populations of $<10^6$ individuals while only 227 species are hyperdominant and account for over half of all trees in Amazonia (ter Steege et al., 2013). Many of these hyperdominants are furthermore only dominant in certain forest types and in certain regions of the basin (ter Steege et al., 2013). Notwithstanding these floristic patterns, it is likely that locals of different ethnicities, ecoregions, and countries share TK associated with many of the hyperdominants. In fact, of the top 20 hyperdominants, seven are palm species, with two showing high levels of TK sharing in our study (*Euterpe precatoria* and *Oenocarpus bataua*) and with cases of shared uses between different ethnic groups for all of the other five species. Collating published data on TK of hyperdominant species and making it available through an international database would be invaluable for the multilateral benefit-sharing mechanisms being developed by the South American Parties to the Nagoya Protocol.

Currently, the state of TK documentation in South America, and possibly in most tropical countries, limits the amount of information that is available for databases that can be used to prevent the granting of patents for non-original innovations (Cámara-Leret et al., 2014a). Thus, it is imperative to document patterns of TK across different scales to understand its structure and to define claims of ownership relevant to the benefit-sharing practices outlined in the Nagoya Protocol. Compiling the remaining TK will be a massive effort that should involve governmental bodies, research institutions, universities, NGOs and villagers. Although the task seems daunting, promising examples exist. For example, countrywide registration of TK is taking place in India through the use of the common methodology of the People's Biodiversity Register, which provides an important base document for legal evidence of prior knowledge (National Biodiversity Authority, 2013). However, for documentation to advance at a greater pace, it is critical to overcome unreasonable regulations faced by scientists studying biodiversity (Gómez-Pompa, 2004) and implement Article 8 of the Nagoya Protocol, which promotes research by simplifying access for non-commercial purposes. Ultimately, by documenting, protecting and wisely managing TK, nations will gain a greater respect for their cultural diversity, strengthen the cultural identity of their ethnic groups, derive benefits for TK custodians, and achieve greater parity between TK and other forms of knowledge.

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Author contributions

RCL, MJM, JCS, HB, and NPZ conceived and designed the study. RCL, NPZ, and MJM performed the fieldwork. RCL analyzed the data. RCL, JCS, HB, and MJM wrote the paper.

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Appendix A. Supporting information

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