



Ecological community traits and traditional knowledge shape palm ecosystem services in northwestern South America



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ABSTRACT

Tropical rainforest ecosystems support the maximum expression of biocultural diversity on Earth and preserving them requires understanding and working with the needs of their inhabitants. Here, we combine traditional knowledge with ecological data to quantify cross-scale variation in the ecosystem services of palms (Arecaceae), the most useful plant family in northwestern South America. We sampled two very large datasets in northwestern South America: one on traditional knowledge ($n = 1494$ interviews) and one on palm ecology ($n = 197$; 0.25 ha-transects) collected in four countries and 47 communities inhabited by >10 Amerindian and non-Amerindian groups, spanning 21° latitude and 14° longitude. We grouped the 47 communities into 15 localities on the basis of geographic proximity and ethnic composition and grouped localities into four sub-regions: northwestern and southwestern Amazon basin, the Andes, and the Chocó. We asked which palm species are most important to villagers and how usefulness is related to the morphological traits of palms, about the cross-scale patterns in palm-based forest usefulness in different sub-regions, localities, and habitats, the relative contribution of different palm growth forms to forest usefulness, and the most valued use categories. We found that despite high geographical variation in traditional knowledge, only a few species were highly important at most localities. On all scales and in most areas, usefulness significantly correlated with stem height, mid-leaf length and fruit diameter, but not with palm abundance. Palm-based forest usefulness peaked in northwestern Amazon and was highest in the Amazon floodplain habitat, but there was large variation on all analyzed scales. Forest usefulness was significantly determined by three palm growth forms and by human food and construction uses. We conclude that palms are key ecosystem service providers that secure the well-being of thousands of inhabitants across northwestern South America. We advocate the need for alliances between forest-dependent people and conservation practitioners to manage these highly useful resources and the ecosystems where they grow.

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1. Introduction

The livelihoods of tropical rainforest inhabitants are inextricably linked to the goods and services delivered by their ecosystems, also known as ecosystem services (Millennium Ecosystem Assessment, 2005). Tropical rainforest ecosystems support the maximum expression of biocultural diversity on the planet (Gorenflo et al., 2012), and preserving them requires understanding and working with the needs of their inhabitants. To a large

extent, inhabitants' traditional knowledge (TK), which consists of past and present beliefs, traditions, practices, and views developed by indigenous and local communities (Huntington, 2000), is a key to accessing, using, and managing ecosystem services. This knowledge is diverse, dynamic, and place-specific. Still, it can also vary among communities and individuals, leading to different methods of obtaining benefits from the same resources (Byg and Balslev, 2004). The benefits that local communities obtain from their surrounding ecosystems are determined by the levels of TK about the classification, ecology, usefulness, and management of natural resources (Phillips et al., 1994), and on the richness, population size, and spatial distribution of species (Luck et al., 2003).

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Much attention has been paid to understanding how the combination of social and ecological factors affects the production of ecosystem services (Reyers et al., 2013). Yet, the extent to which humans depend on ecosystem services across spatial scales and different population groups remains poorly understood (Yang et al., 2013). Scholars increasingly recognize the importance of integrating scientific knowledge and TK (Huntington, 2011). This approach bridges knowledge systems and facilitates processes of knowledge co-production to improve decision-making for management (Armitage et al., 2011).

Palms (Arecaceae) are an excellent model group for a study that integrates ecology and TK in order to determine the importance of ecosystem services on multiple spatial scales and with different population groups in South America. Palms are among the most abundant plant families in the tropical rainforests of South America. Some palm species are hyperdominant, and palms constitute a major proportion of the above ground biomass (ter Steege et al., 2013). In addition, many palms are “cultural keystone species” (Garibaldi and Turner, 2004) because they (i) have intense levels of use (Barfod and Balslev, 1988), (ii) have a multiplicity of uses (Balslev et al., 2008; Macía et al., 2011), (iii) have names and associated terminology in indigenous languages (Marmolejo et al., 2008), (iv) are prominent in narratives, ceremonies, and dances (Schultes, 1974), (v) are ubiquitous in the collective cultural consciousness (Cámara-Leret et al., 2014), (vi) are difficult to replace with other available native species, and (vii) are used as items of trade with other groups (Brokamp et al., 2011). Given their abundance, usefulness, and marketability, palms are intensely harvested, but mismanagement is common (Bernal et al., 2011).

Over the past few decades, scholars have sought to determine how useful plants influence native and non-native cultures (Prance et al., 1987; Phillips et al., 1994; Macía et al., 2001; Torre-Cuadros and Islebe, 2003), often to support conservation of South American rainforest habitats (Phillips et al., 1994). These studies have shown beyond a doubt that palms are the most useful plant family (Prance et al., 1987; Phillips et al., 1994). In the lowland *terra firme* forests of the Peruvian Amazon, a positive relationship exists between species usefulness and geographic range size (Ruokolainen and Vormisto, 2000). In lower montane forests (800–1000 m elevation) in south-eastern Ecuador, abundance and palm height positively correlate with usefulness (Byg et al., 2006). Another study using data from bibliographic references and herbarium specimens from the Ecuadorian Amazon (<500 m elevation) found that palm stem height, stem diameter, and fruit diameter positively correlate with the number of palm uses (de la Torre et al., 2009). Despite substantial advances, all of these studies employed different methods and were restricted in spatial scope, preventing conclusions on regional scales.

Here, we provide the first multiple-scale study on palm ethnobotany in the northwestern South American region, and possibly the world. Our study region ranks second in palm diversity globally (Dransfield et al., 2008) and is populated by a multiplicity of indigenous Amerindian groups and non-Amerindian groups of mixed ethnic origin (Lewis et al., 2013), whose livelihoods depend on forest-based products. As little is known about the ecosystem services of palms in other regions besides the Amazon, we included the tropical rainforests of the Andes and Chocó and investigated the TK of some of the human groups inhabiting them. Both of these regions are known to harbor hyper-diverse palm communities.

The overall objective of this study was to integrate TK about the usefulness of palms and ecological data to determine the distribution of palm-based ecosystem services on multiple spatial scales. Specifically, we asked the following questions: (1) Which palm species are most important to villagers and how is their usefulness related to their morphological attributes? (2) Are the patterns of forest usefulness similar across sub-regions, localities, and habi-

tats? (3) What are the relative contributions of different palm growth forms to forest usefulness? (4) Which use categories are most important to villagers? Based on our findings, we evaluated the priorities necessary for future conservation plans in the region. To the best of our knowledge, this study is the first attempt to compare the ecosystem services of a keystone family across northwestern South America or any other region of the world.

Understanding large-scale spatial patterns in the distribution of palm-based ecosystem services on multiple scales will allow policymakers and managers to focus on species that make the greatest overall contribution to human livelihoods, prioritize conservation actions in habitats/sub-regions where palm ecosystem services are greatest, and direct more resources to areas where TK on palms is highest and, thus, where a danger of greater cultural erosion exists.

2. Methods

2.1. Study area

Our research was carried out in northwestern South America within the Amazon, Andes, and Chocó on three nested spatial scales: sub-regions, localities, and habitats (Fig. 1).

The four sub-regions were (i) northwestern Amazon, comprising areas in Colombia, Ecuador, and Peru east of the Andes at elevations below 1000 m and north of 5°S; (ii) southwestern Amazon, comprising areas in Peru and Bolivia east of the Andes at elevations below 1000 m and south of 5°S; (iii) the Andes, comprising the montane forests of Colombia and Peru above 1000 m; and (iv) the Chocó, comprising humid rainforests along the Pacific coast of Colombia and northwestern Ecuador (Fig. 1).

The 15 localities were defined on the basis of geographic proximity of communities with ethnobotanical interviews to the communities with palm transects (Table 1). Localities were inhabited by the following human groups: (i) Amerindian, dominated by one Amerindian group; (ii) multiethnic, mixed settlement of several Amerindian groups; (iii) mestizo, dominated by people of mixed origin whose parents were generally of European–Amerindian descent; (iv) Afro-American, dominated by Black Americans of African ancestry; and (v) heterogeneous, mixed settlement of Amerindians and non-Amerindian groups (i.e., mestizos and/or Afro-Americans). The five sampled localities in the northwest Amazon sub-region are mostly inhabited and legally owned by Amerindians; they are vast and only accessible by rivers, and most are located far from markets. In contrast, the six localities in the southwest Amazon contain a greater proportion of non-Amerindian people and of private lands, access is mostly by roads and markets are close. Within the Chocó sub-region, the Colombian study locality is populated and owned by Afro-Americans. In the Ecuadorian Chocó, both Amerindians and non-Amerindians coexist in close proximity, and land tenure is a mixture between collectively owned Amerindian lands and private property. Both Chocó localities are accessible by roads and located close to markets. The remaining two Andean localities are inhabited by Amerindians and accessible by roads. The Colombian Andean site is located in a valley that harbors several large towns, has a mixture of private and indigenous lands, and is immersed in the market economy. In contrast, at the Bolivian site Amerindians are the exclusive owners of vast lands and villages are farther from markets.

The 15 localities covered eight habitats: (i) Amazon floodplain, including floodplain and swamp forests; (ii) Amazon non-inundated; (iii) Amazon pre-montane hills, located on the eastern flank of Andean foreland forests at elevations of 300–550 m; (iv) Chocó floodplain; (v) Chocó non-inundated; (vi) Chocó pre-montane hills, located on the western flank of Andean foreland forests at eleva-

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