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Research

A Biodiversity Informatics Approach to Ethnobotany: Meta-analysis of Plant Use Patterns in Ecuador

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ABSTRACT. We explored the relative importance of ecosystem diversity, socioeconomic, environmental, and geographical factors in determining the pattern and diversity of people's plant use in Ecuador, based on existing ethnobotanic investigations and a large database of georeferenced plant collections. For each of 40 communities, we determined the number of plants used and their distribution among 12 use categories. Plant species richness of the ecosystem surrounding each village was determined using herbarium data and rarefaction. Variation in socioeconomic, environmental, and geographical indicator variables at the community level was summarized using Principal Component Analysis (PCA). Data were then analyzed using multiple regression and ordination analysis. We found a significant positive relationship between the number of plant species used and ecosystem species richness, whereas socioconomic, environmental, and geographical factors had no significance. However, ordination analysis did show a clear link among these factors and plant use patterns, i.e., the relative importance of different use categories. Study communities were divided into two groups: 1) Andean and coastal communities with better access to public services and markets categorized by high scores in these use classes: medicinal, social, food additives, environmental, apicolous (of economic interest in apiculture), and toxic to nonvertebrates; and 2) Amazonian remote communities with high scores for these use classes: food, fuel, materials, vertebrate and invertebrate food, and toxic to vertebrates. Our findings suggest that economic and social development affects plant use patterns in a selective way. Some traditional uses will persist despite increased infrastructure development and habitat disturbance, whereas others that reflect subsistence strategies dependent on conserved natural habitats may soon disappear. The study incorporates more than 20 years of ethnobotanical research effort and a combined herbarium specimen database with more than 250,000 georeferenced records. As such, it provides a first example of how a biodiversity informatics approach can be used to take ethnobotanical analysis to new and larger scales.

Key Words: *ecosystem diversity; human–plant interaction; plant species richness; socioeconomic, environmental, and geographical factors*

INTRODUCTION

It is intuitively plausible that human communities that inhabit ecosystems rich in species also use a high number of species, and several studies have demonstrated just such a relationship (e.g., Begossi 1996, Salick et al. 1999, Begossi et al. 2002, Ladio and Lozada 2003, Ladio and Lozada 2004, Medley and Kalibo 2007, Thomas et al. 2008, de la Torre et al. 2009). Other studies have emphasized social, cultural, socioeconomic, and geographical factors as the main controllers of the number of species used by human communities (Ladio and Lozada 2001, Vandebroek et al. 2004, Byg et al. 2007).

Among nonbiotic factors that influence how local people use wild plants, market access appears to be one of the most important ones (Sierra et al. 1999*a*, Lawrence et al. 2005, Gray et al. 2008). Increasing market integration may lead to resource degradation or to the replacement of forest-based activities by nontraditional activities, some of which, such as cattle raising, result in forest clearing that, in turn, leads to a reduction in the number of wild species that are accessible to the communities affected (Sierra et al. 1999*a*, Godoy et al. 2005). The degree of market integration depends on factors such as the availability of, and distance to, markets and roads (Pan and Bilsborrow 2005, Byg et al. 2007). Access to government services and infrastructure such as schools, health, electricity, or telephones may also affect the degree of reliance on plant resources, as well as the way they are used, which will translate into the use of fewer species from the surrounding ecosystem (Benz et al. 2000, Gray et al. 2008). For example, it has been shown that education, or homogenizing mass-media products such as radio and television, can increase acculturation and loss of traditional practices in plant use (Benz et al. 2000, Sternberg et al. 2001, Pan and Bilsborrow 2005). Finally, variables such as population density, urbanization, migration, and labor mobility may reduce the number of species extracted for use from the surrounding vegetation (Browder 2002, Rudel et al. 2002, Gray et al. 2008). For instance, higher population density and progressing urbanization often translates into higher environmental impacts and less availability of natural habitats (Pautasso 2007, Gray et al. 2008). Therefore, integration into global market economies and subsequent decreased reliance on forest resources may have a stronger impact on the number of plants and the way they are used than ethnicity or historical factors such as the period of time that a community has occupied a certain area (Lawrence et al. 2005, de la Torre et al. 2009).

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Here, we test the relative importance of ecosystem species richness, and socioeconomic, environmental, and geographical factors, in determining the number of plant species used by people, along with the relative importance of different use categories. To do so, we compare data from a series of ethnobotanical inventories from Ecuador with data on ecosystem species richness derived from very large botanical databases. Ecuador provides an ideal case for testing general hypotheses regarding the relationship between people's plant use, and ecological and cultural diversity. It is a megadiverse country with 46 vegetation types (Sierra et al. 1999*b*) and more than 17,000 vascular plant species (Ulloa Ulloa and Neill 2005, Jørgensen et al. 2006). Moreover, the country is inhabited by 17 different cultural groups, including indigenous people and "mestizos," that is, those of mixed racial origin, who have interacted with a variety of ecosystems that differ highly in their species richness. Most groups live in rural communities that actively interact with the biological diversity of the surrounding ecosystem, as demonstrated by the fact that one third of all Ecuadorian plant species are being used by people (de la Torre et al. 2008).

Ethnobotanical research has a long tradition in Ecuador (de la Torre and Macía 2008), dating back to the 18th century (de Velasco 1978, Estrella 1991). The last three decades in particular have seen a multiplicity of ethnobotanical studies, some focusing on specific use categories (e.g., Estrella 1988, Acosta-Solís 1992) or ethnic groups (see references in Table 1). In the same period, the methodological approach has changed considerably, from descriptive–narrative to quantitative–synthetic, allowing a better understanding of the patterns of plant use, and also producing much more complete ethnobotanical inventories (e.g., Paz y Miño et al. 1991, Cerón and Montalvo 1998, Báez 1999, Macía et al. 2001, Macía 2004, Cerón et al. 2005*a*, *b*).

Within the framework described above, we were specifically interested in understanding 1) whether the number of plant species used by rural communities is related to the diversity of plants in the surrounding ecosystem, 2) whether there is a parallel influence of socioeconomic, environmental, and geographical factors on the number of species used, and 3) how the pattern of plant use, i.e., the relative frequency of different use categories such as food, medicine, materials, etc., changes in relation to these factors.

METHODS

Ethnobotanical Information

Data concerning numbers of species used, along with use categories, was compiled for 40 communities across Ecuador (Fig. 1) based on published and unpublished studies (Table 1). These 40 communities were selected from a pool of more than 100 sites in Ecuador where ethnobotanical studies have been conducted, and are those with the most complete data. Of the 40 communities selected, 33 were studied by the Ecuadorian ethnobotanist Carlos Cerón using a uniform methodology. Data were compiled from publications and one unpublished thesis, and supplemented by additional information from Cerón's field books and herbarium vouchers collected in connection with the studies (Table 1). All data were entered in a database on Ecuadorian plant uses (de la Torre et al. 2008).

To control for sampling effort, the 40 communities were divided into two categories, according to the duration of field work and the techniques employed. Category 1 communities (n=19) represented an intermediate study effort. All of these were studied by Cerón during 5–15 days of fieldwork, and included a number of 0.1–0.5 ha transects established to collect herbarium specimens and record plant names and uses from local informants. Category 2 communities (n=21) represented the highest study effort, and we estimate that these inventories are nearly complete, regardless of some variation in the methodology applied. Fourteen Category 2 communities were studied by Cerón, during 30–100 days of fieldwork in each community. Data collection involved semistructured interviews, and the establishment of transects (0.1–0.5 ha), permanent plots (1 ha), and paths (usually 2 km long) in representative vegetation types surrounding the community, in areas where all plants being used had been identified by local informants. A more detailed description of Cerón's methods is given in Appendix 1. The remaining seven Category 2 communities (Table 1) have been the subject of very intensive studies published by other authors. For each community, from the ethnobotanical data we extracted the number of plant species used. In addition, we assigned each use reported to one of 12 use categories (Cook 1995, as modified by de la Torre et al. 2008). These categories are: 1) food, 2) food additives, 3) vertebrate food, 4) invertebrate food, 5) apicolous (of economic interest in apiculture), 6) fuel, 7) materials, 8) social, 9) toxic to vertebrates, 10) toxic to nonvertebrates, 11) medicinal, and 12) environmental. A detailed definition of these categories is provided in Appendix 2.

Ecosystem Plant Species Richness

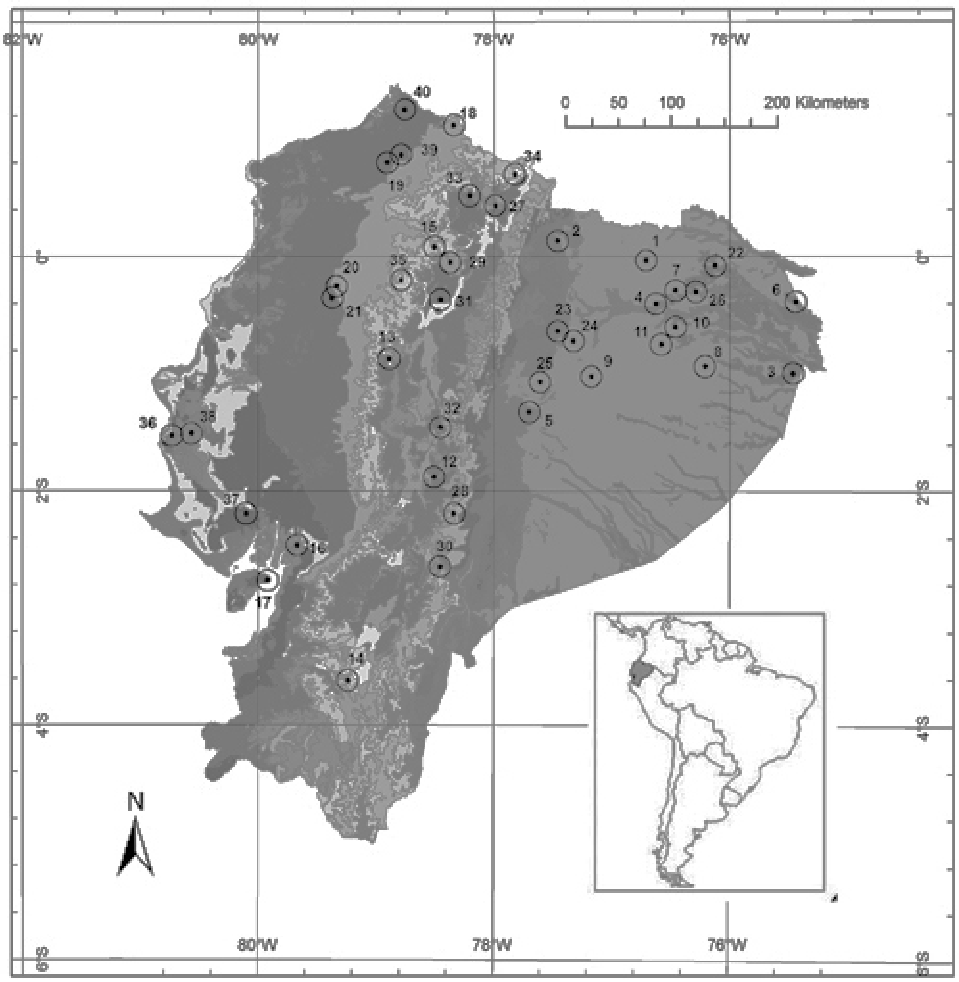
To estimate the species richness of the ecosystem surrounding each community, we first compiled a database with 262,295 georeferenced herbarium specimen records from Ecuador, combining data from the herbarium databases of the Missouri Botanical Garden (MO), including collections from the National Herbarium of Ecuador (QCNE), Aarhus University (AAU) Pontificia Universidad Católica del Ecuador (QCA), and Universidad Central del Ecuador (QAP). Note that herbarium acronyms have been provided following the Index Herbariorum of the New York Botanical Garden. We then determined all vegetation types present within 10 km of the communities where the 40 ethnobotanical studies had been made. For this, we used Sierra et al.'s (1999*b*) vegetation map, which

Table 1. Ecuadorian localities selected for the assessment of determinants of their plant use richness and use patterns.

No.	Locality	Study category†	Region	Ethnic group	Source
1	Dureno	2	Amazon	Cofan	Cerón 1995, C. E. Cerón (*personal observation*‡)
2	Sinangue	2	Amazon	Cofan	Cerón et al. 1994*a*, C. E. Cerón (*personal observation*)
3	Jatuncocha	2	Amazon	Kichwa of the Amazon	Cerón 2003, C. E. Cerón (*personal observation*)
4	Limoncocha	2	Amazon	Kichwa of the Amazon	Cerón et al. 2005*c*, C. E. Cerón (*personal observation*)
5	Oglan	2	Amazon	Kichwa of the Amazon	C. E. Cerón (*personal observation*)
6	Copal	2	Amazon	Secoya	Cerón et al. 2005*a*,*b*, C. E. Cerón (*personal observation*)
7	San Pablo	2	Amazon	Secoya	Cerón et al. 2005*a*,*b*, C. E. Cerón (*personal observation*)
8	Dicaro	2	Amazon	Wao	Macía et al. 2001
9	Quehueiri-ono	2	Amazon	Wao	Cerón and Montalvo 1998, C. E. Cerón (*personal observation*)
10	Tiputini	2	Amazon	Wao	Macía et al. 2001
11	Yasuni	2	Amazon	Wao	Cerón and Montalvo 2002*a*, C. E. Cerón (*personal observation*)
12	Alao	2	Andes	Kichwa of the Andes	Cerón and Montalvo 2002*b*, C. E. Cerón (*personal observation*)
13	Quilotoa	2	Andes	Kichwa of the Andes	Cerón et al. 1994*b*, C. E. Cerón (*personal observation*)
14	Saraguro	2	Andes	Kichwa of the Andes	Ellemann 1990
15	Pululahua	2	Andes	Mestizo	Cerón 1993*a*, C. E. Cerón (*personal observation*)
16	Manglares Churute	2	Coast	Mestizo	C. E. Cerón (*personal observation*)
17	Puna	2	Coast	Mestizo	Madsen et al. 2001
18	San Marcos	2	Coast	Awa	Barfod and Kvist 1996, A. Barfod and L. P. Kvist (*personal communication*)
19	Zapallo Grande	2	Coast	Chachi	Barfod and Kvist 1996, A. Barfod and L. P. Kvist (*personal communication*)
20	Chiguilpe	2	Coast	Tsa'chi	Cerón et al. 2004, C. E. Cerón (*personal observation*)
21	Congoma Grande	2	Coast	Tsa'chi	Barfod and Kvist 1996, A. Barfod and L. P. Kvist (*personal communication*)
22	Cuyabeno	1	Amazon	Cofan	Cerón et al. 2006, C. E. Cerón (*personal observation*)
23	Guagua Sumaco	1	Amazon	Kichwa of the Amazon	Cerón 1993*b*, C. E. Cerón (*personal observation*)
24	Huiruno	1	Amazon	Kichwa of the Amazon	Cerón 1993*b*, C. E. Cerón (*personal observation*)
25	Jatun Sacha	1	Amazon	Kichwa of the Amazon	C. E. Cerón (*personal observation*)
26	Sehuaya	1	Amazon	Secoya	Cerón et al. 2005*a*,*b*, C. E. Cerón (*personal observation*)
27	Ambuqui	1	Andes	Mestizo	Cerón and Montesdeoca 1994, C. E. Cerón (*personal observation*)
28	Upano	1	Andes	Mestizo	Cerón 2002*a*, C. E. Cerón (*personal observation*)
29	Guayllabamba	1	Andes	Mestizo	Cerón and Montesdeoca 1994, C. E. Cerón (*personal observation*)
30	Loma San José	1	Andes	Mestizo	C. E. Cerón (*personal observation*)
31	Pasochoa	1	Andes	Mestizo	C. E. Cerón (*personal observation*)
32	Pondoa	1	Andes	Mestizo	Cerón 2002*b*, C. E. Cerón (*personal observation*)
33	Salinas	1	Andes	Mestizo	Cerón and Montesdeoca 1994, C. E. Cerón (*personal observation*)
34	San Gabriel	1	Andes	Mestizo	Cerón and Pozo 1994, C. E. Cerón (*personal observation*)
35	Chiriboga	1	Andes	Mestizo	C. E. Cerón (*personal observation*)
36	Agua Blanca	1	Coast	Mestizo	Cerón 1993*c*, C. E. Cerón (*personal observation*)
37	Cerro Blanco	1	Coast	Mestizo	Cerón 2002*c*, C. E. Cerón (*personal observation*)
38	San Sebastian	1	Coast	Mestizo	Cerón 1993*c*, C. E. Cerón (*personal observation*)
39	Playa de Oro	1	Coast	Afroecuadorian	Cerón 2001, C. E. Cerón (*personal observation*)
40	Guadualito	1	Coast	Awa	Cerón and Montalvo 2002*c*, C. E. Cerón (*personal observation*)

†"Study category" refers to the sampling effort intensity as described in the methods section.
‡"Personal observation" or "personal communication" indicates that published information was complemented by unpublished data compiled from field books and herbarium sheets.

Fig. 1. Vegetation map of Ecuador (Sierra et al. 1999*b*) and location of the 40 study localities.†



†Numbers refer to Table 1.

recognizes 46 major vegetation types in Ecuador mapped as polygons. A 10 km radius was chosen as an approximation of the range in which most human harvesting of natural plant resources occurs (Zapata et al. 2006, Pautasso 2007). Finally, we selected all herbarium specimens collected within the vegetation polygons touched by the 10 km radius circle and used these to determine ecosystem plant species richness. The vegetation-type approach was chosen instead of a method based on predefined grids or circles, to compensate for the scarcity of herbarium specimens at smaller scales, while at the same time avoiding inclusion of vegetation types beyond the reach of a community. Differences in plant collection intensity were compensated for by using rarefaction in EcoSim 7 software (Gotelli and Entsminger 2008). Species richness was determined from subsamples of 800 specimens, which was the maximum number of specimens available for all sample points. For a few Category 1 communities, the ethnobotanical effort was specifically directed toward a subset of the vegetation types surrounding the village. In this case, ecosystem species richness was estimated only on the basis of the polygons defined by the vegetation types covered by the study.

Additional Explanatory Variables

To estimate the effect of socioeconomic, environmental and geographical factors on the number of plant species used, we derived 13 indicator variables for each of the 40 studied communities (Table 2) from the most recent national population census (Instituto Nacional de Estadísticas y Censos 2002), the Integrated System of Social Indicators of Ecuador (Sistema Integrado de Indicadores Sociales del Ecuador 2005), and the Monitoring Socio-environmental System of Ecuador (Ecociencia 2002). A detailed description of these variables is provided in Appendix 3. Most variables were scored at the level of the "cantón," as this is the smallest political division in Ecuador for which such data exist. Geographical variables, including the distance to a main market, the distance to the province capital, and road access, were scored for each community using the Ecuador road network map (Dirección Nacional de Recursos Naturales Renovables del Ecuador 2002).

Statistical Analysis

Given strong co-linearity among the socioeconomic, environmental, and geographical indicator variables, we performed a principal components analysis (PCA; Legendre and Legendre 1998), maintaining only components with eigenvalues >1.0. These components were then used in a second step to model the number of plants used.

Table 2. Rotated principal components that reduced colinearity among 13 socioeconomic, environmental, and geographical indicator variables of 40 studied localities in Ecuador.†

Component	1	2	3
Eigenvalue	8.48	1.70	1.06
Percentage of variance	65.20	13.06	8.15
Cumulative percentage of variance	65.20	78.25	86.40
Loadings of variables			
Electricity access	0.61†	-0.61†	-0.27
Telephone access	0.86†	-0.15	-0.42
Tap water access	0.76†	-0.27	-0.36
Health index	0.93†	-0.15	-0.22
Uncovered basic needs index	-0.89†	0.30	0.25
Education index	0.93†	-0.19	-0.28
Urban population	0.83	-0.33	-0.20
Population density	0.91†	-0.06	-0.18
Vegetation remnancy index	-0.25	0.93†	0.21
Vegetation fragmentation index	-0.13	0.94†	0.23
Market distance	-0.26	0.27	0.79†
Province capital distance	-0.23	0.12	0.86†
Road access	0.35	-0.27	-0.70†

† Represents the highest loadings of each ordination axis.

The number of plant species used was regressed against ecosystem plant species richness and the three principal components using standard OLS multiple regression. Prior to statistical analysis, the variable "number of plant species used" was log transformed to secure a normal distribution of residuals. We analyzed Category 1 and Category 2 communities together, including study type as a categorical variable to control for the general difference in level of study intensity. As results from Category 1 communities are assumed to be more prone to error caused by sampling artifacts, we also analyzed Category 2 communities separately.

A principal component analysis (PCA) ordination of 38 studied communities was conducted to explore use patterns, i.e., the distribution of use records on use categories, and the relationship between ordination axes and predictor variables. Information about use patterns was lacking for two communities (Dicaro and Tiputini) and, thus, they were excluded from this analysis. Data on use records were arcsinh transformed to obtain a normal distribution, as recommended by Fowler et al. (1998) for count data with zeros. The relationship between the ordination axes and the descriptor variables was analyzed using Spearman's rank correlation. All statistical analyses were carried out in JMP 7 software (SAS Institute).

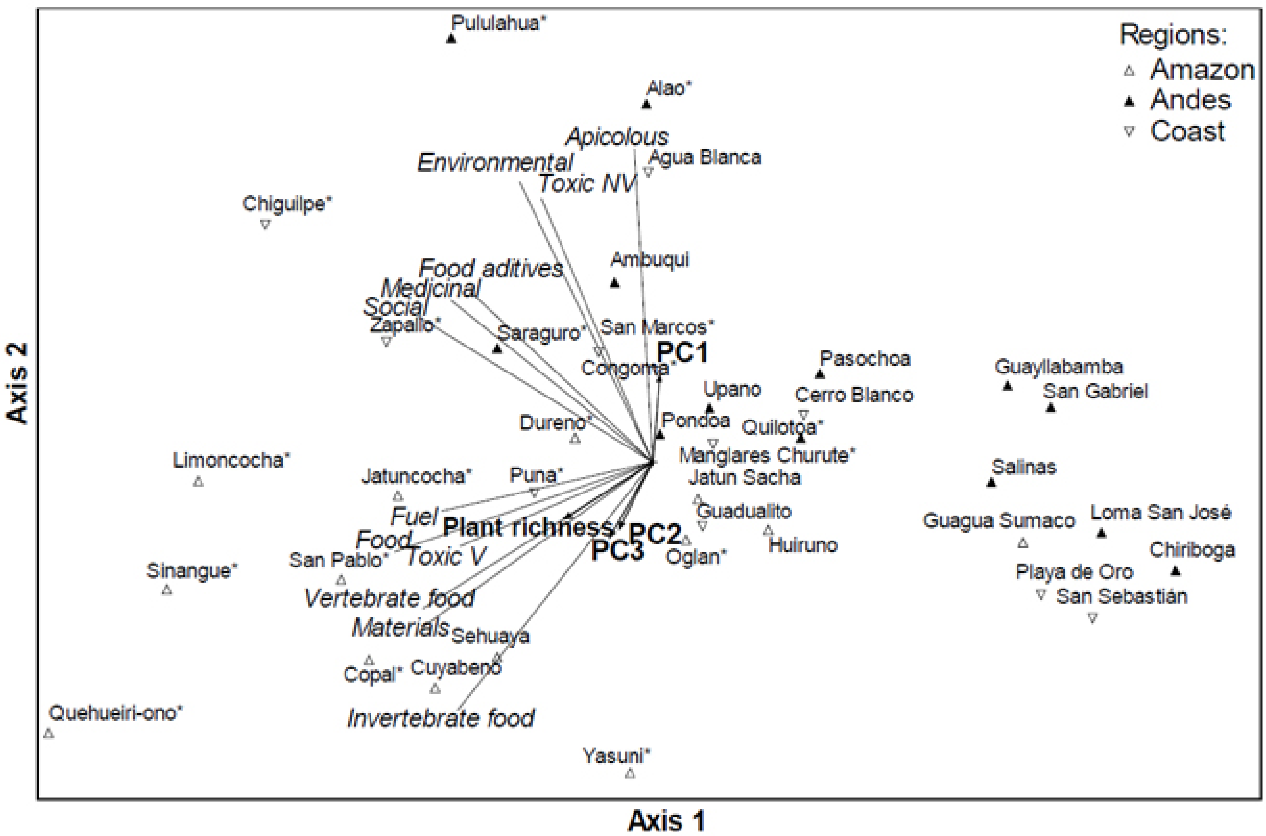
RESULTS

The number of plant species used by the communities varied from 32 in San Gabriel, an Andean mestizo locality at 3000 m elevation, to 636 in Quehueiri-ono, a lowland Amazon indigenous locality. Principal component analysis of 13 socioeconomic, environmental, and geographical indicator variables resulted in three components with an eigenvalue >1.0 (Table 2). The first component, expressing "infrastructure development and population density," correlated positively with the electricity access, telephone access, tap water access, health index, education index, urban population, and population density variables, and negatively with the uncovered basic needs index. The second component, expressing "natural habitat conservation," correlated positively with vegetation remnancy and fragmentation indices. The third component, expressing "remoteness of the community," correlated positively with market and province capital distances, and negatively with road access.

A multiple regression model (Table 3) showed that ecosystem plant richness had a highly significant positive effect on the number of plant species used, both when all 40 communities were analyzed (Category 1 and 2) and when only intensively studied communities (Category 2) were analyzed. The study type, i.e., Category 1 or 2, also had a significant effect in the analysis of all 40 communities, whereas the three principal components extracted from socioeconomic, environmental, and geographical indicator variables had no significant effect in either analysis.

Ordination analysis (Fig. 2) grouped communities into two clusters along the first and second ordination axes. Together, these two axes explained 63.6 % of the variance in the dataset. The first ordination axis gave a separation between communities with high study intensity (Category 2) and medium study intensity (Category 1). The second ordination axis separated a cluster of mostly Amazonian communities with high usage in these categories: "food," "fuel," "materials," "vertebrate," "invertebrate food," and "toxic to vertebrates" from one including mostly coastal lowlands and Andean communities with high frequencies in these categories: "medicinal," "social," "food additives," "environmental," "apicolous," and "toxic to nonvertebrates".

Fig. 2. Biplot of the PCA ordination performed for the plant use patterns (distribution of use records on use categories) of 38 Ecuadorian localities.†



†Notes:

Axis 1: Eigenvalue = 5.7; percent of variance explained = 47.6.

Axis 2: Eigenvalue = 1.9; percent of variance explained = 16.0.

Bold arrows represent correlations between ordination axes and variables listed in Table 3.
Ordinary lines represent correlations between use categories of Cook (1995) as modified by de la Torre (2008) and ordination axes.

Toxic NV=Toxic to nonvertebrates.

Toxic V=Toxic to vertebrates.

Otherwise, full names of the use categories are given in the Figure.

A detailed explanation of use categories is given in Appendix 2.

Category 2 studies are marked by an asterisk (*) after the community name.

The first axis was significantly negatively correlated with ecosystem plant species richness (r_s=-0.4 P < 0.05). The second axis was significantly positively correlated with PC1 reflecting infrastructure development and population density (r_s=0.37 P < 0.05), and negatively with PC2 and PC3 reflecting natural habitat conservation (r_s=-0.3 P < 0.05) and remoteness of the community (r_s = -0.5 P < 0.05).

Table 3. Effect of ecosystem plant species richness, socioeconomic, environmental, geographical, and methodological factors on plant use richness among 40 Ecuadorian localities.

Parameter	All communities n=40	Category 2 communities n=21
Model R-sq.	0.67**	0.43*
Intercept	0.12	0.74
Ecosystem plant species richness	0.0016*	0.0029*
PC 1: Infrastructure development and population density	-0.00027	-0.012
PC 2: Natural habitat conservation	0.038	-0.0063
PC 3: Remoteness of the community	0.039	0.076
Study category	0.46**	N/A

Significance levels: *p<0.05, **<0.001.

DISCUSSION

Number of Plant Species Used

The hypothesis that there is a positive relationship between the number of plant species used by a human community and the number of plant species present in the surrounding ecosystem is strongly supported by our results. To estimate ecosystem plant species richness, we used a large data set with close to 300,000 georeferenced herbarium collections. Museum data sets represent one of the best and largest sources of information on past and present biodiversity (Soberón and Peterson 2004), regardless of limitations resulting from potentially biased collecting efforts and the heterogeneity of sampling approaches (Lira-Noriega et al. 2007). We circumvented these limitations by using a very large botanical database, combined with rarefaction techniques, to estimate ecosystem plant richness in polygons of the vegetation types available for each locality.

The lack of standardized sampling techniques in ethnobotanical studies has previously hampered comparative studies (Reyes-García et al. 2007). Here, we use a large ethnobotanical dataset collected by a single researcher with a uniform technique supplemented with data from a few very intensively studied communities, which allowed us to extract the required information with a high degree of precision. In addition, we divided the studies into two categories according to sampling effort, and analyzed these both together and separately. This made it possible to demonstrate a statistically significant effect of ecosystem plant species richness in modeling the number of plant species used by a particular people, despite the added variance introduced by sampling artifacts.

We found no significant role for socioeconomic, environmental, and geographical indicators in explaining the number of plant species used by a community. However, such a role has been explicitly pointed to by other studies. Specific factors highlighted have included the remoteness of a community and its market access (Ladio and Lozada 2001, Byg et al. 2007); these have been cited as factors that explain the number of plant species used by a community irrespective of the levels of diversity of the surrounding ecosystem. This difference may have arisen because the cited studies focused only on currently practiced uses, rather than on all plant uses known to a community. Under changing livelihood conditions where new commodities or plant supplies become available through increased market access, modernization, and habitat destruction, the current uses of plants would be affected immediately, whereas all plant uses known to a community would remain constant until cumulative plant use knowledge changes over changing generations (Byg and Balslev 2001, Godoy et al. 2005, Reyes-García et al. 2005).

The ethnicity of the studied communities could potentially influence both the number of species used and their distribution among use categories, given different historical traditions (Atran et al. 1999, Ladio and Lozada 2001, Byg et al. 2007). Here, we were not able to address this question explicitly, given that the 21 Category 2 communities in our study represent eight different indigenous ethnic groups, so there would not be enough replication for statistical analysis. Only three of these intensively studied communities are “mestizo,” i.e., represent a mixture between Spanish and (mostly) highland indigenous culture. The 19 Category 1 communities included in our analysis represent six different ethnicities, but the majority are mestizo (n=12). Therefore, a general difference between indigenous and mestizo culture in our data would be confounded by the uneven representation of these two groups among the two categories of study types. The low representation of mestizo communities among the intensively studied communities provides a clear illustration of the general need to consider more than just indigenous communities in remote areas when planning ethnobotanical studies if general conclusions are to be achieved (Lawrence et al. 2005).

Plant Use Patterns

Unlike the number of species used, the distribution of uses among different categories showed a clear relationship to the three principal components extracted from socioeconomic, environmental, and geographical indicator variables. The use pattern also demonstrated a clear relationship to the number of species in the ecosystem where the communities are located. Thus, the main contrast found in our ordination analysis was one between well-connected Andean and coastal communities located in less diverse, more densely populated and disturbed environments, and isolated Amazonian communities with less access to services and markets, but surrounded by more species-rich, less populated, and better conserved ecosystems.

The use categories prevalent in Andean and coastal communities, that is, “medicinal,” “social,” “food additives,” “environmental,” “apicolous,” and “toxic to nonvertebrates,” possibly persist under increasing levels of infrastructural development because they address needs that are unaffected by changing livelihoods. One example is medicinal uses. A large part of the medicinal plants reported in Ecuador are herbaceous (de la Torre et al. 2008) and grow successfully in disturbed areas (Zimdahl 1999) and, therefore, remain available in disturbed habitats. Many societies in the Andean and coastal regions have a long contact history with western society, and exhibit higher population density and a sedentary way of life (Ayala 1995). All of these factors have been associated with higher levels of illness and, consequently, an increased demand for medicinal plants (Davis and Yost 1983*a*, Voeks 2004). Traditional medicine in the Andes and coastal lowlands is also maintained because it is used not only by rural residents but also by urban populations of all social classes, and a wide variety of medicinal plants are sold in markets in cities and towns across the country (Bussmann and Sharon 2006, Cerón 2006). Finally, cultural tradition may perhaps explain the persistence of some of these uses. For example, the Tsa'chi healers in the area around Santo Domingo de los Colorados in the coastal plain are considered the best “curanderos” in Ecuador, receiving patients from all over the country, and they even travel abroad to heal (Barfod and Kvist 1996, Cerón et al. 2004).

Other use categories prevalent in the Andes and the coastal lowlands can probably be explained in much the same way. “Food additives” in Ecuador are mainly herbs used as condiments; many of them are introduced, cultivated, and even commercialized (Van den Eynden and Cueva 2008). Therefore, the use of plants for this purpose thrives well in urban environments. The “toxic to nonvertebrates“ use category includes plants that eliminate domestic insects that are highly important in precarious urban conditions with high population density, such as fleas, cockroaches, or mosquitoes, or to combat agricultural pests associated with market-oriented agriculture. Apiculture has been promoted by the Ecuadorian government as a source of income in rural areas of the dry coastal lowlands and Andes (Refinca 2008). Several apicolous plants are cultivated in Ecuador and the same species may be used for other commercial purposes such as for food, e.g. fruits of *Coffea arabica, Citrus* spp., *Rubus niveus, Carica papaya, Persea americana,* animal fodder (*Medicago sativa*) or wood (*Eucalyptus* spp.) (Carpio and Barragan 2008). The “environmental” use category includes mainly plants used in agroecosystems, i.e., for the establishment of living fences, fertilization through nitrogen fixation, and as ornamentals. Ornamental use has been related to increased market integration and lowered dependence on basic forests resources (de la Torre et al. 2009).

In contrast, the dominant use categories in Amazonian communities, that is, “food,” “fuel,” “materials,” “vertebrate” and “invertebrate food,” and “toxic to vertebrates,” reflect a higher dependence on forest resources in areas with less access to modern services and commodities. Most of the material culture of the communities in the Amazon is based on forest resources. Plants are used for the construction and thatching of houses, for the manufacture of household utensils, agricultural tools, and articles for hunting and fishing. The less contact the group has had with the outside world, and the more remote it is, the greater is the association to these uses. For example, the Wao, the most recently contacted group, were traditionally seminomadic people that roamed large interfluvial areas hunting and gathering forest products while maintaining itinerant gardens (Davis and Yost 1983*b*). They stand out for the diversity of wild edible plants they use, mainly fruits, seeds, and palm hearts (Davis and Yost 1983*b*, Macía et al. 2001, Macía 2004). Like other Amazonian groups, they have an intimate knowledge of their prey animals (de la Torre et al. 2008), which is reflected in our data by a high frequency score for the “vertebrate food” category. The Wao are also recognized for the quality of their “curare” dart poison (Trupp 1981), which is so well known that other indigenous groups prefer to use it rather than using their own (Cerón and Montalvo 1998).

CONCLUSION

We have shown that the number of plant species used by a community is strongly associated with the number of species found in the ecosystem that surrounds it, whereas socioeconomic, environmental, and geographical factors, such as increased levels of market integration, education, access to public services, and habitat disturbance influence the ways in which plants are used in the communities. Together, these two findings provide a strong argument for the conservation of natural plant resources by stressing the general use value of plant diversity. At the same time, our work suggests that this value may be preserved as a society develops and changes its use patterns. Our study brings together decades of botanical and ethnobotanical investigation in Ecuador using a biodiversity informatics approach. Despite limitations intrinsic to museum collection data, we were able to reveal patterns at a country level from many individual and localized previous studies. Biodiversity informatics represents a new way of practicing ethnobotany, with great potential to contribute to a better understanding of questions that have already been asked, while also fostering the ability to address exciting new questions.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol17/iss1/art15/responses/

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APPENDIX 1.

An overview of the ethnobotanical field studies conducted by Carlos Cerón in the period 1993-2005.

General methodology

Key informants were designated by members of the community according to their ethnobotanical knowledge. The number of informants varied from 1-11. After identification of the informants the location of representative patches of the different vegetation types available to the community was decided in collaboration with community members.

For category 0 studies data were gathered through random plant collections done with local informants who were interviewed informally during visits to paths and areas close and around the communities. For category 1 and 2 studies a plot-based semi-structured interview procedure was applied. The research team consisting of Carlos Cerón and at least one assistant walked together with the key informant(s) through transects, plots or paths (see table 1 below). Useful plant species were identified by the informants. Each identification was followed up by a semi-structured interview regarding starting out with same two basic questions: 1) What is this plant for? 2) Which part of the plant is used for that purpose? Several uses could be recorded for the same plant. Additional information that was offered during the conversation initiated by the two basic questions (i.e. preparation, harvest data, history) was also recorded, but this part of interview did not follow a predefined scheme. In each case a herbarium voucher for the identification of the plant was collected and prepared during the conversation.

Table A1.1. Overview of studies and their characteristics

Study category	**0**	**1**	**2**
Number of communities	88	19	14
Study regions	Andes (86), Amazon (2)	Andes (9), Coast (5), Amazon (5)	Andes (3), Coast (2), Amazon (9)

Ethnicity	Mestizo (76), Kichwa of the Andes (10), Kichwa of the Amazon (1), Shuar (1)	Mestizo (12), Kichwa of the Amazon (3), Cofan (1), Secoya (1), Awa (1), Afroecuadorian (1)	Kichwa of the Amazon (3), Mestizo (2), Kichwa of the Andes (2), Wao (2), Cofan (2), Secoya (2), Tsa'chi (1)
Duration of field work	Usually one weekend	5 –15 days	30 –100 days
Methodology	Random plant collections done with local informants who were interviewed informally during visits to paths and areas close and around the communities.	Data recorded in transects (0.1 – 0.5 ha)	Data recorded in transects (0.1 – 0.5 ha) and/or permanent plots (1 ha) and/or by walking along paths (usually 2 km long) in representative vegetation types surrounding the community
Notes	The studies were performed mainly during weekends and by Carlos Cerón's undergraduate students. Type 0 studies are not included in the analysis as we judge the information too incomplete for our purpose	Commonly, these studies were conducted to assess the plant diversity and composition of the locality. Ethnobotanic information was a secondary priority but still thoroughly documented.	In these studies the gathering of ethnobotanical data was the main focus

APPENDIX 2.

Description of the 12 use categories as defined by Cook (1995) and modified by de la Torre et al. (2008) and used in this study for classifying plant use records.

Use category	Description
Food	Plants eaten by human beings. Include plants used to make beverages
Food additives	Processing additives and other additive ingredients used in food or beverages preparation
Vertebrate food	Forage and fodder for domestic or wild vertebrates that serve as a source of food for human beings
Invertebrate food	Plants eaten by invertebrates that are useful to humans, such as edible grubs
Apicolous	Plants that provide pollen, nectar or resins as sources for honey or propoleum production. This category was separated from invertebrate food due to its importance in developing countries as Ecuador
Fuel	Plants used to produce charcoal, or used as petroleum substitutes, alcohols, or tinder
Materials	Plants used as source of materials for construction of houses, fences or bridges, or to elaborate handicrafts, music instruments, work tools, weapons, home objects, etc. This category includes fibers, waxes, oils, chemicals and their derived products
Social	Plants used for cultural purposes, which are not definable as food or medicines. This category includes hallucinogens, contraceptives and plants with ritual or religious significance. Plants used to cure cultural disorders as “bad air” are also included
Toxic to vertebrates	Plants that are poisonous to vertebrate animals, both accidentally and when deliberately applied, such as extracts and preparations used for fishing and hunting
Toxic to non vertebrates	Plants that are poisonous to non vertebrates, both accidentally and when deliberately applied. This category includes insecticides and herbicides
Medicinal	Plants used to cure human and animal sicknesses
Environmental	Plants used to protect, improve, and fertilize soils; to provide shadow, as living fences, ornamentals or that form a structural part of agroforestry systems

APPENDIX 3.

Description of the 13 socioeconomic, environmental, and geographical variables of 40 studied localities in Ecuador.

Name	Description	Level	Source
Socioeconomic			
1. Electricity access	Percentage of households in cantón with electric service	Cantón	INEC 2002
2. Telephone access	Percentage of households in cantón with telephone	Cantón	INEC 2002
3. Tap water access	Percentage of households in cantón with access to a public net of tap water	Cantón	INEC 2002
4. Health index	A composite indicator combining information about health infrastructure, availability of potable water, quality of sewer system, level of malnutrition and population mortality	Cantón	SIISE 2005
5. Uncovered basic needs index	A composite indicator expressing the lack of access to education, good nutrition, housing, electricity, tap water, and sewage system plus employment opportunities and degree of overcrowding	Cantón	SIISE 2005
6. Education index	A composite indicator combining information about alphabetization rates, access to schools and average years of school attendance	Cantón	SIISE 2005
7. Urban population	Percentage of people living in urban centers	Cantón	INEC 2002
8. Population density	Number of people per km^2	Cantón	INEC 2002
Environmental			
9. Vegetation remnancy index	Area of remnant natural vegetation in the cantón divided by the total area of the cantón.	Cantón	Ecociencia 2002
10. Vegetation fragmentation index	The ratio between the total area of remnant natural vegetation polygons (in km^2) in the cantón and their perimeter in (km).	Cantón	Ecociencia 2002

Geographical			
11. Market distance	Straight line distance (log transformed) from the community to the main market available when the ethnobotanical study was carried out. The variable is an indicator of the market opportunities of the localities population, considering both the relative cost of bringing products to markets and the level of stimulus that a market provides to change production and consume patterns	Community	DINAREN 2002
12. Province capital distance	Straight line distance (log transformed) from the community to the province capital. Represents the degree of isolation of the locality with respect to governmental institutions (often located in the province capital) as well as distance to big commercial markets.	Community	DINAREN 2002
13. Road access	Number and quality of roads available for each community in a radius of 10 km. In weighting road quality a two-lane asphalted road was given a value of 4; an one-lane asphalted road was given a value of 3; a two lane dirt road was given a value of 2; and a one-lane dirt road was given a value of 1. The final value of road access was found by summing up values across all roads available to the community.	Community	DINAREN 2002