The search of human-driven patterns of global plant diversity: why and how?

Edgardo I. Garrido-Pérez [1,2] & Peter Glasnović [3]

[1] Centro de investigaciones botánicas, herbario y jardín botánico; Universidad Autónoma de Chiriquí, Urbanización El Cabrero, Carretera Interamericana, David, Chiriquí, Panamá. edgardoga2@hotmail.com

[2] Universidad Regional Amazónica –IKIAM, El Tena, Napo, Ecuador
[3] Insitute for Biodiversity Studies, Science and Research Center of Koper, University of Primorska. Garibaldijeva 1, 6000 Koper-Capodistria, Slovenia. Peter.Glasnovic@zrs.upr.si.

(Received: April 16, 2013. Accepted: November 22, 2013)

ABSTRACT. Humans are the main agents of ecological change, so studying how they pattern plant diversity is necessary to complement knowledge already achieved by global research on non-intervened forests. Humans are a multiple role animal with roles ranging from seed predation and herbivory to ecosystem engineering by urbanizing and mining. According to Natural selection and Life-history theories thick-coated and thick-barked species may profit from recurrent use of fire; epipetric species may profit after urbanization but field studies confirming these and other predictions are scarce. The unified neutral theory of biodiversity and biogeography provides an attractive null hypothesis, particularly for places with human-depleted diversity, where many species may be similarly pre-adapted to strong disturbances. Seedlings and saplings in the past were susceptible to environmental change ranging from tree-fall gap to large scale habitat modification by humans. Also juveniles are exposed to disturbances like being cut by humans or openings around large trees during logging so secondary forests of today are historical legacies of human activities. International coordinated studies on secondary forests around the world, with repeating methods already used for old-forests, are needed to quantify how humans alter plant macroecological patterns. Ecological information spread in historical, archaeological, anthropological, geographical and other sources can be extracted while identifying the actors (people), factors (biotic and non biotic) and driving forces (e.g. institutions) of forest change for different periods. To convert such information into numbers, as econometricians do, and test how it describes plant diversity and species composition, may help to address how *Homo sapiens* globally affects plant diversity. This job is easier for places in Mediterranean countries (e.g. Slovenia) than in the tropics (e.g. Brazil) because of the uneven quality of available information. Direct historical evidence is more available in the Mediterranean while ethno-ecological methods seem more applicable for the Tropics.

RESUMEN. Los humanos son la principal causa de los cambios ecológicos y por ello es necesario estudiar cómo alteran los patrones de diversidad vegetal, a fin de complementar lo que ya se sabe gracias a los inventarios florísticos mundiales realizados en bosques no intervenidos. Los humanos constituyen una especie multifacética que juega papeles que van desde la depredación de semillas y la herbivoría hasta la ingeniería de ecosistemas por medio del urbanismo y la minería. De acuerdo con las teorías de la Selección Natural y las Estrategias de Historia de vida, las especies vegetales con semillas y tallos con cubierta gruesa deberían ser favorecidas por la aplicación recurrente del fuego mientras las especies epipétricas deberían beneficiarse por la urbanización. Sin embargo, los estudios de campo sometiendo a prueba estas y otras predicciones son escasos. La Teoría Neutral Unificada de la Biodiversidad y la Biogeografía provee una hipótesis nula atractiva, particularmente para los lugares donde los humanos han degradado la diversidad vegetal, pues allí muchas especies de plantas pueden estar similarmente preadaptadas a los disturbios severos. En el pasado, las plántulas y brinzales fueron susceptibles a cambios ambientales que iban desde la formación de claros hasta la modificación en gran escala del hábitat por los humanos. También, los juveniles están expuestos a disturbios tales como ser cortados por los humanos o la apertura de espacios en torno a árboles grandes durante la tala selectiva. Por ello los bosques secundarios de hoy son un legado histórico de las actividades humanas. Se necesitan investigaciones coordinadas internacionalmente que inventaríen los bosques secundarios en todo el mundo, usando los métodos ya aplicados para los bosques maduros, a fin de cuantificar los patrones macroecológicos causados por los humanos. Existen valiosas informaciones ecológicas dispersas en fuentes históricas, arqueológicas, antropológicas, geográficas y otras. Dichas informaciones pueden extraerse identificando los actores (las personas), factores (bióticos y abióticos) y las fuerzas conductoras (e.g. instituciones) de cambio ambiental para distintos períodos en el pasado. Convirtiendo esa información en números, tal como hacen los econometristas, y averiguando si esos números son buenos descriptores de la diversidad y composición de especies vegetales inventariadas se puede ayudar a evaluar mejor cómo el *Homo sapiens* afecta la diversidad vegetal mundial. Esta labor es más fácil para países del Mediterráneo (e.g. Eslovenia) que para los países tropicales (e.g. Brasil) debido a la desigualdad en la calidad de las informaciones disponibles. La evidencia histórica directa es más fácil de lograr en el Mediterráneo, mientras que los métodos y aproximaciones etno-ecológicas parecen aplicarse mejor a los trópicos.

KEY WORDS. Biodiversity surveys and patterns, econometrics, first law of geography, land-use history, macroecology.

Humans have been shaping forests and the whole planet since tens of thousands of years in a process we now call Global Change (Crutzen & Stoermer 2000). According to such authors anthropogenic disturbance and landscape transformation result from activities like the following: hunting and gathering, agriculture and livestock, urbanization, industry, and mining. Post-disturbance field abandonment jumped from less than 50 million- to more than 200 million hectares around the world during the second half of the XX century (Cramer *et al*. 2008). Thus, economic growth and land abandonment throughout history allowed our world of abundant "primary" forests to become increasingly replaced by a world of secondary forests and other impacted areas (Guariguata & Ostertag 2001). Global, regional, and local patterns of plant diversity and species composition may be ruled by the variation of human impact across land-use histories. Processes like climatic variation, plant-plant competition, plant-soil interactions, seed dispersal, island biogeography, and others are widely accepted as drivers of plant diversity (see review in Wright 2002). Still a remaining challenge is to discover human-driven patterns of biodiversity for a better understanding of Global Change.

Plant ecologists have been studying global biodiversity patterns since about the late 1970's, when Alwyn Gentry started to survey the forests of the world (Phillips & Miller 2002). To date more than 600 forest plots (0.1 ha each) have been surveyed. Results had been recorded in different databases such as the *Alwyn Gentry* (Phillips & Miller 2002) and *SALVIAS* (Synthesis and Analysis of Local Vegetation Inventories Across Scales), as well as the *Forest Plots* database which comprises >300 1-ha plots (Phillips *et al*. 2003). There are also 47 forest plots, usually ranging from 4 to 30 ha with some of them ≥50 ha (http://www.ctfs.si.edu/). These plots have been censused every five years as part of the Smithsonian Institution Global Earth Observatory project (*SIGEO*) pioneered by the Center for Tropical Forest Science-*CTFS* (Condit 1995). The above mentioned projects are probably the most reliable sources of information on how forests change according to varying factors across the Earth because they use consistent, standardized methods for monitoring plant diversity and forest dynamics. The projects also represent a wide range of habitats, from boreal to tropical forests, although some biomes like mediterranean forests are very poorly represented. However, a great majority of the studied plots are located in forests minimally affected by humans. Other efforts like the Long Term Ecological Research Network (http://www.lternet.edu/network) include some secondary forest stands but it's still mainly restricted to the United States of America.

To be sure, we recognize that current worldwide forest plots studies provide very valuable information on the effects of major processes like Climate Change. For instance, Condit (1998) and Engelbrecht *et al*. (2007) showed that intensified drought reduced the populations of species that require more water than others on Barro Colorado Island's 'primary' forest. Global patterns of plant diversity are largely known and discussed based on virtually non-human intervened forests (see Phillps & Miller 2002 and the works by Alwyn

Gentry). Besides empirical results, sound theories like The Unified Neutral Theory of Biodiversity and Biogeography (Hubbell 2001) come out of forest research plots like the here mentioned. An expansion of the world-wide network of forest plots by adding secondary forest plots to these projects is needed to fit the results to an already changed planet. Our planet is a collection of places with different climates and ecologists have already achieved regression models predicting the number of woody plant species according to climatic information (Clinebell *et al*. 1995, van der Heijden & Phillips 2009). Our planet is also a collection of places with different land-uses potentially holding quantitative patterns of plant diversity and species composition change resulting from human impact around the world.

Assessing the effect of humans on global plant diversity

There are basically three ways to assess the importance of humans as drivers of plant diversity. One is experimentally simulating land-uses like slash-and-burn agriculture, keeping control plots without such disturbance, allowing the vegetation to coppice, and checking which plant species from the pre-disturbance condition resprout better (Sampaio *et al*. 1993, 1998, Mamelde & Araújo 2008). This would require many decades to fully check what species grow and reproduce successfully. Another option is to use computer-simulations of human impacts on ecological variables thereby providing hypotheses on future scenarios of Global Change (Shugart *et al*. 1992, Bondeau *et al*. 2007). The third option, seldom used, is the one we discuss here: to consider the history of humankind, as a human-nature interaction experiment, occurring in places of the world with different climates and soils. According to this approach, researchers can get socio-economic and historical information corresponding to the surroundings of each studied forest plot in different places of the world. Such numerical information can be put in statistical models like Linear Regression or Structural Equation Modelling to test for the relative importance of climate change *vs.* land-use as drivers of plant diversity. A similar approach is successfully used for econometric studies (Goldberger 1972, McCallum & Austin 2000) and in ecological studies detecting predictors of species richness in coastal wetlands (Grace & Pugsek 1997) and Neotropical forests (van der Heijden & Phillips 2009). To our knowledge, however, it has never been used to assess global plant diversity and how humans affect it.

In this review we start by applying basic ecological concepts to human-forest interactions assuming *Homo sapiens* as an animal like any other. Then we answer the following questions: (1) What are the biological reasons why History can be used as an auxiliary science in order to quantify the relative importance of climate change *vs.* land-use as drivers of plant diversity?, (2) How can the theories of Natural Selection, Life-History Strategies, and the Unified Neutral Theory of Biodiversity and Biogeography (Hubbell 2001) successfully guide studies quantifying human-driven patterns and processes of biodiversity?, (3) How can ecologists use skills from Geography to convert information from History and other social sciences into data to be tested as descriptors of biodiversity?, and finally, (4) What are the challenges in converting historical information into data for ecologist and how to cope with such challenges for a better understanding of Global Change?

Basic ecology of human-forest interactions

Humans as a multi-role animal. Homo sapiens plays roles comparable to other biotic elements of forests (Table 1). By extracting seeds and timber, humans act as seed predators and herbivores. By clear-cutting and burning, humans consume plant biomass as natural catastrophes like fire and hurricanes also do.

Table 1. Five ecological roles of humans potentially altering the patterns and dynamics of plant diversity.

Human activities	**Ecological equivalents**
Extraction of seeds	Seed predation
Leaf extraction, selective logging, burning	Herbivory; disturbance forming gaps
Clear-cutting	Large-level disturbance (e.g. hurricanes)
Hunting carnivore- and herbivore animals	Top-down alteration of trophic structure
Damming, tillage, soil removal, hill's size reduction, mining, replacing soil with cement and other solid structures	Ecosystem engineering, geological change

When hunting, humans reduce carnivores and herbivores populations altering top-down regulation processes that determine the relative abundance of plant species. By selectively planting plants or by keeping certain plant species in fields and yards (Toledo *et al*. 2003) humans give those species an advantage and can favour the populations of such plants with respect to other species. Selective logging generates gaps; these enhance local plant diversity by transforming the forest in a mosaic that includes both pioneer and long-lived plant species (Denslow 1987). By letting cows, goats and other livestock to freely forage near and inside forests (Leal *et al*. 2003) humans interfere in the effects of herbivory on plant diversity: moderate grazing by livestock enhances plant diversity with respect to no grazing and intense grazing (Naveh & Withaker 1979). By clear-cutting and keeping clear-cut areas open, humans delay or even stop secondary succession, and alter biodiversity and ecosystem functions like biomass accumulation and biogeochemical cycles (Cramer *et al*. 2008). Moreover, hydrological and geological changes like damming rivers, tilling, mining that reduces the size of hills, and replacing soil with cement are ways by which the ecosystem engineered by *H. sapiens* may differentially favour some plant species. For instance, species adapted to rocky microhabitats are pre-adapted to grow on cement and may profit from urbanization better than non-epipetric species. Humans, however, perform practices that potentially counteract their large-scale disturbance. Performing mosaics of fallow, crops, perennial agroforestry and old-grown forests by traditional agriculture practices in single landscapes enhances biodiversity with respect to intensified land-uses reducing landscape complexity (Tscharntke *et al*. 2005). Remnant trees kept by humans after clear cutting (e.g. as live fences or sources of shade and fruits) are used by birds perching and feeding on them increasing the chances of seeds transported by such animals from nearby forests to fall and sprout (Guariguata & Ostertag 2001). Actively planting trees plays a similar role but also protects seedlings against hot temperatures and herbivores in semi-arid regions, particularly when the nursed plants have spines or form tangles (Zamora *et al*. 2004). All these may facilitate succession (see also Connell & Slatyer 1977). Thus, *H. sapiens*' provoked global change does not catch basic Ecology unprepared: Ecology does have ways to understand and study the mechanisms by which humans alter plant diversity. Such studies are the core of Human Ecology and Conservation Biology and should be added into basic Ecology for a better understanding of plant communities subjected to Global Change.

Why should Plant Ecology rely on History?

Woody plants as witnesses of history. In order to become adults, trees conforming today's forests had to pass through a sequence of juvenile stages throughout many decades (Martínez-Ramos 1994). Seedlings and saplings in the past were susceptible to environmental change ranging from tree-fall gap to large scale habitat modification by humans (see also Moles & Westoby 2004), juveniles are exposed to disturbances like -for instance, being cut by humans for fencing or openings around large trees to facilitate climbing (Garrido-Pérez & Gerold 2009). That is why past events altering the species composition of seedlings and juveniles are most likely the cause of today's patterns of forest diversity and species composition. Also tropical woody vines (lianas) are considered disturbance specialists proliferating after logging, clear-cutting and other human-induced disturbance (see review in Schnitzer & Bongers 2002); which makes lianas potentially good indicators of previous land-use in the tropics (Garrido-Pérez & Gerold 2009).

Global Change: a historically uneven process. Macroecology considers the world as a collection of places with uneven climates and soil characteristics patterning plant diversity, distribution, and species compositions (van der Heijden & Phillips 2009). The world should also be considered a collection of forest stands with different land-use histories and distances to nearby human settlements with different socio-economic characteristics. Such socio-economic data and their values during different historical periods can be used as descriptors of plant diversity besides classic ecological variables like annual rainfall and soil characteristics. This is possible because Global Change develops unevenly in space and time. For example, urbanization and over-grazing by domestic livestock started earlier in the Middle East, where many large animals were already domesticated, than in other regions. Sheep, goats, and cattle were domesticated 10-11 thousand years ago in Eastern Asia (Zeder 2008) while llamas and alpacas were domesticated 6-7 thousand years ago (Wheeler 1995). Also North-Eastern Brazil was subjected to large-scale monoculture and grazing by livestock much earlier than other regions like the Amazon (Fausto 1999) but much later than in Europe. This may have resulted in different degrees of land-use-induced depletions of biodiversity, quantifiable by further world-wide surveys on secondary forest.

Actors, factors and driving forces of land-use. Land-use changes result from decisions taken by humans during their interactions with nature. These decisions are considered to depend on biotic, non-biotic, technological, and political-institutional-cultural conditions acting as *driving forces* of ecological change (Brandt *et al*. 1999, Bürgi *et al*. 2004). For example, if people easily find food and other resources inside forests, there is a lack of chain saws, and no government promotes deforestation, then humans will probably decide to keep the forest as many hunters and gathers do. In contrast, when a government promotes large-scale monoculture and livestock, deforestation is then promoted (e.g. Fausto 1999), changing land-use, and altering the structure and dynamics of plant communities. Thus, there are interactions between the *actors*, *factors* and *driving forces* of land-use change (modified from Bürgi *et al*. 2004). Actors are humans directly altering forests; factors are the biotic and non-biotic conditions constraining the effectiveness of human decisions on how to alter forests. Driving forces are the socioeconomic, political, technological, cultural-traditional and other determinants of local-level-taken decisions on how to use land (Table 2).

Table 2. Driving forces affecting human-plant community interactions (modified from Brandt *et al*. 1999, and Bürgi *et al.* 2004). Examples are taken from North-Eastern Brazil and Slovenian Sub-Mediterranean forests.

Types of forces	Examples
Socioeconomic.	Market pressure; e.g. Multi-national pharmacological company Merck and Brazilian consumers buying faveira (*Dimorphandra gardneriana*) and piqui (*Caryocar coriaceum*); wine and olive consumers in Slovenia.
Political.	Rules, laws and authorities limiting resource exploitation. Also local and national authorities, lobbyists influencing decision makers determining use and distribution of resources (e.g. water and land).
Technological.	Roads and highways facilitating the access to forests. Means of transportation (from donkeys and bicycles to trucks and ships). Distance to roads, rivers and the sea. Tools used for getting the resources (e.g. machete *vs.* chain saw).
Culture and tradition.	Learn from ancestors when, where and how to look for resources or planting crops.
Randomness and individual freedom.	Falling in love with someone living far away may determine men to stay out of the target forest area.

Let us exemplify the later with an example from Brazil. Before the arrival of the Portuguese, the main actors of land-use in NE-Brazil were natives practicing diversified economic activities including hunting and gathering inside forests. Selective logging and slash-and-burn polyculture on fields that were later abandoned were probably the most relevant disturbances. Newcoming Portuguese replaced the actors by introducing sugar cane planters who were supported by a foreign driving force namely the crown of Lisbon (Teixeira 1993). The decision on what to plant was constrained by factors like climate and soil, which were appropriate for sugar cane instead of grapes or strawberries. The result was a dramatic replacement of forests by monoculture and increasingly larger human settlements that have lasted for the past 500 years (Teixeira 1993). Since planting and harvesting sugar demand burning, large scale clear-cutting and fire for keeping permanently open areas became the main mechanisms of disturbance applied by *H. sapiens*. Similar situations occurred in many areas of the world. This example illustrates how ecologists can consult historical information but also evidence from Archaeology, Sociology and even old documents, to identify the actors, factors, and driving forces determining land-use change, to deduce the main disturbances occurring in any given area of interest.

Solid theories for studying human-driven biodiversity change

Natural selection and Life-history strategies. Natural selection filters different adaptations of living beings to disturbance. For example, some plants have thick-barked trunks and seeds as well as fast-coppicing capabilities. Humans did not intervene in the evolution of those plants, but such species are better pre-adapted to re-sprout after slash-and-burn agriculture (Sampaio *et al*. 1993, 1998, Garrido-Pérez & Gerold 2009). Direct use of plant resources by humans can also totally or partially harm plant bodies resulting in different degrees of risks of reducing plant population. Using a whole stem for housing, as well as extracting whole seeds to produce oil, implies to kill a whole individual, directly reducing the population of that species compared to other species. In contrast, extracting some leaves (e.g. to make infusions) implies less damage to each plant and its population. This occurs in places like Laje do Carrapicho and surroundings, Pernambuco, Brazil, where different organs of more than 75 plant species are used by people (Albuquerque & Andrade 2002). In addition, plant species have different life-history traits and adaptive strategies for different degrees of disturbance, ranging from short-lived, light-demanding pioneers to slow-growing, shade tolerant species (Denslow 1987, Martínez-Ramos 1994). Pioneers would be better adapted to space-opening by humans compared to shade tolerant species that have better chances when their seeds are under the shade of trees or small forest patches (Zamora *et al*. 2004). These well known theories managed by ecologists may help to hypothesize how different plant species living in a stand today occupied and persisted there as a consequence of past human activities.

The Unified neutral theory of biodiversity and biogeography. Since its full introduction by Hubbell (2001) the Unified Neutral Theory of Biodiversity and Biogeography (UNTBB) provided random ecological drift as a solid null hypothesis able to improve Ecology. One of the assumptions of the UNTBB is that birth, mortality and dispersal of plant individuals composing a community are similar across species on a per-capita basis; all these resulting in species turnover occurring as a random walk (see also Rosindell *et al*. 2011) instead of processes like interspecific competition or human intervention. The role of chance as a driver of plant diversity has been argued as easily falsifiable by empirical data (McGill *et al*. 2006). Precisely because of that we consider it a good null hypothesis to explore which impacts by humans better describe plant diversity by producing significant departures from randomness; an application of UNTBB as an Ockham razor already proposed (Hubbell 2008). The original UNTBB was considered particularly plausible for plant species belonging to the same guild (e.g. pioneers) (Hubbell 2001) and is pointed as functional across guilds (Rosindell *et al*. 2011). Places of the world subjected to recurrent, human-made disturbance during many centuries like The Mediterranean Basin, North Eastern Brazil, Western Europe, the Middle East, Africa, The Caribbean and Mesoamerica may have suffered a depletion of species less adapted to disturbance in the past. If this is true, then the species composition, relative abundance and species turnover in such forests may fit better to randomness than to deterministic patterns following natural, historical or socio-economic variables. Further studies may test this.

Niche-assembly theories are more difficult to be falsified than the UNTBB. For instance, the role of competition as a major force in plant species turnover is so difficult to be tested that ecologists used to say that current patterns of plant diversity and species composition result from a *ghost* called *competition in the past* (Begon *et al*. 2008). The sole existence of competition is difficult to be demonstrated (Connell 1990) making it hard to test the relative importance of land-use with respect to competition as determinants of biodiversity. Also, the myriads of combinations of probabilities of land-use applied by each individual farmer before land abandonment makes it difficult to find easily predictable trajectories during secondary succession from the point of view of niche-assembly theories (Chazdon 2008). Indeed we consider UNTBB, rather than competitive exclusion, as a more parsimonious cause of biodiversity patterns to be tested *vis-a-vis* human disturbance in the past.

Quantifying socio-historical information

Geography helps test relationships between distance to human settlements-and infrastructures *vs.* forest characteristics. For instance, the coverage and number of forest patches declines in places located closer to roads and cities in North Eastern Brazil (Santos & Tabarelli 2002); similar results have been found in Eastern United States (Wear *et al*. 1998) and for soil characteristics (Pouyat *et al*. 2008). These discoveries confirm the First Law of Geography applied to human-forest relationships: things near to each other are more related to each other compared to a third thing located farther away (Tobler 1970). Thus, ecologists can collect historical information on human impacts and socio-economics of human settlements in the past; locate on maps the places where that occurred, and then explore whether distances from the current forest to past events and infrastructure are correlated. Something similar has been successfully implemented to describe plant diversity in urban environments (Hope *et al*. 2003).

The following information can be collected on the human settlements near surveyed forest plots. All distances can be both Euclidean and following the shape of routes like trails and roads measured on current and old maps. (1) Population size of nearby human settlements and historically influential cities, towns, and villages. For historical periods where numbers are not available, total houses may be a proxy. (2) Distance to historically influential cities, towns and villages other than the human settlement nearest to the surveyed plot. (3) Degree of integration of the human settlement to larger economic centres. For periods where data on import-export earned money are not available, size of roads and highway may be a proxy. (4) Number of non land-working consumers (e.g. soldiers, priests) in the nearest human settlement. (5) Distance to the nearest communication route: trail, road, highway, railroad, navigable rivers and sea.

Obstacles to study forest history

Europe: the easy way of cadastres. The very well documented European history facilitates land-use history reconstruction. For example, there are detailed cadastre maps of the whole Austro-Hungarian Empire, including Slovenia, since early XIX century (Petek & Urbanc 2004), making it possible for ecologists to survey virtually any plot in a forest, settle its coordinates, and then look into the old cadastres and maps for easily reconstructing the land-use history of the stand. Other, useful maps are the ones by Homman (1714), Kindermann (1818), Kozler (1853), and Austria's Bibliotek allgemeinen und praktischen Wissens fur Militäranwärter (1905). Some of these maps also show vast areas of the Austro-Hungarian Empire to which Slovenia belonged for centuries. Many maps include roads, schools, churches, population size and other socio-economic information that could be tested as descriptors of current biodiversity (Kindermann 1818). Similar amounts of accurate information are available for countries like the United States of America where land-use history has been published in detail (e.g. Matlack 1997). But although Europe has more historical data available to be tested as descriptors of current biodiversity, Europe lacks quantitative data on forest stand diversity to be used as response variable in such tests. Two reasons are the following: (1) Continental European forests surveys follow widely different methods across countries and periods (Corona & Marchetti 1998, Bundesministerium für Ernährung, Landwirtschaft, und Verbraucherschutz 2006, Šilc 2006, Kovac & Hocevar 2010). (2) Some applied methods generate semi-qualitative indicators of species abundance (Poore 1955), making it impossible to statistically test a number of macroecological predictions.

Countries lacking cadastres. Many tropical countries had been largely ruled by foreign powers interested in tax-paying, precise accounting, and good statistics and maps of their properties and those of their enemies. Two examples are the Portuguese and the Dutch who generated precise maps of Brazil like the ones by Montanus (1605), van der Aa (1729), and Pinto (1813), but such maps and data are scarce and comparatively less precise. Other information, like accounting data related to agriculture and livestock productivity is largely elusive. Central governments, both before and after the independence, always found difficulties to achieve detailed information. For example, de Mello (2004) and Neto (2009) report cases of NE-Brazilian landlords successfully facing the official police and army by contracting bandits. Counterband was intensively practiced by local businessmen and local rulers in detriment of the Spanish Crown in Mexico, Panama, Peru and other colonies (Gasteazoro *et al*. 1980) suggesting poor effectiveness of central government's control, as well as a poor, or even absent, local interest in cadastre maps and statistics in order to better avoid taxes. Also universities and even the printer were prohibited in Brazil for many centuries as a way to avoid the rise of political rivals by means of improved culture (Fausto 1999). As a by-product, there are very few, difficult-to-find books and information on colonial Brazil and land use (e.g. Cabral 1801) compared to other countries (e.g. Herrera 1752). Population censuses started very late in some countries; for instance 1872 in Brazil (Teixeira 1993); in some countries the census were (and still are) manipulated to prepare confusing polls (Falola & Heaton 2008). Deducing land-use history-reconstruction demands the concentration of information spread over different sources, thus inviting ecologists to assume the challenge in a multidisciplinary way.

Historians practicing the so-called *Total history* take the population, landscapes and other natural and socio-economic characteristics into account and exhaustively search for such information (e.g. Gasteazoro *et al*. 1980) making it simpler for ecologists to read their work while distinguishing actors, factors and driving forces of human-forest interactions. Some chroniclers have correlated vegetation characteristics and land use; for example de Landa (1556) explained forest materials used for housing by Mayans in the Yucatan Peninsula, Mexico. Other original reports by colonial explorers (transcribed in Gasteazoro *et al*. 1980) enlist forest, farm, and yard plant species used in diverse areas of Panama during the XVIII century. Also archaeologists have found at least 12 woody plant species in five different coprolites dating from 8500 to 7000 years before present day in Brazilian Semi-Arid region (Chaves & Reinhard 2006). Settlements of rebelled maroons, their life styles and land uses, have also been well documented (e.g. Diggs 1940-1956, Gasteazoro *et al*. 1980). Other studies compare the diets of both slaves and masters in tropical colonies (Lensink 2008) making it possible to deduce land-use patterns according to the way of production of each eaten item. Thus, descriptive historians and archaeologists, better than interpretative ones, supply more concentrated information for ecologists to reconstruct land-use histories.

Another pre-eminently open-air activity documented by historians is warfare. During war officers seriously take land characteristics into account for better guaranteeing their supplies and facing the enemies. Indeed, some military historians provide valuable information on lands and their transformation by military engineers (Traas 2010), and forests as shelters for enemies as well as farms as sources of supplies (Reed 1964, de Mello 2004 and references therein). They also provide some descriptions of the terrain and its transformation before and after war (Ribas 2009), and lists of battle scenarios and commanders (Macaulay 1978) making it possible to look for land descriptions into the memories written by the latter, facilitating the tracking of habitat characteristics where historical processes occurred. A great deal of land-use history is also achieved by interviewing elder people (e.g. Garrido-Pérez & Gerold 2009). This and other methods borrowed from Ethnobotany and Ethnoecology are increasing their accuracy. For example, subjectivities can be reduced by separately interviewing different persons, and then detecting consensus across informants (Gerhardinger *et al*. 2010, de Medeiros *et al*. 2010) about the facts occurred and land characteristics as well as locating the information on chronologies and maps. Thus, in spite of the elusive nature of data in some countries, ecologists can concentrate the information and infer land-use history by tracking ecological information spread over different sources of information.

ACKNOWLEDGEMENTS

This paper largely resulted from EIG-P's visits to Brazil's Federal Rural University of Pernambuco-Laboratory of Applied Ethnobotany, and Slovenia's University of Primorska-Institute for Biodiversity Studies; EIG-P deeply appreciates facilities and hospitality there. María del Pilar Angulo and Virginia Vélez proofread and supplied valuable suggestions to the manuscript.

LITERATURE CITED

Albuquerque, U.P. & L.H.C. Andrade. 2002. Uso de recursos vegetais da caatinga: o caso do agreste do Estado de Pernambuco (nordeste do Brasil). Interciencia 27:336–346.

Beagon M., C.R. Townsend & J.L. Harper. 2008. Ecology: from individuals to ecosystems. Malden (MA): Blackwell Publishing Ltd. pp. 227-265.

Bibliothek allgemeinen und praktischen Wissens für Militäranwärter Band I. 1905. Österreich-Ungarn Karte. [on line]. <http://commons.wikimedia.org/wiki/File:OesterreichUngarn.png> [March 2013].

Bondeau, A., P.C. Smith, S. Zaehle, S. Schaphoff, W. Lucht, W. Cramer, D. Gerten, H. Lotze-Campen, C. Müller, M. Reichstein & B. Smith. 2007. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Global Change Biology 13:679–706.

Brandt, J., J. Primdahl & A. Reenberg. 1999. Rural land-use and landscape dynamics –analysis of 'driving forces' in space and time. *In*: R. Kronert, J. Baudry, I.R. Bowler & A. Reenberg (eds.). Land-use changes and their environmental impact in rural areas in Europe. UNESCO, Paris, France. pp. 81-102.

Bundesministerium für Ernährung, Landwirtschaft, und Verbraucherschutz (Germany). 2006. Survey instructions for the 2nd National Forest Inventory (2001-2002). [on line] <http://www.bundeswaldinventur.de/media/archive/513.pdf> [March 2013].

Bürgi, M., A.M. Hersperger & N. Schneeberger. 2004. Driving forces of landscape change –current and new directions. Landscape Ecology 19:857-868.

Cabral, V.J.D. 1801. Coleção das observações dos productos naturais do Piauí ao ilmo e exmo Sor. D.Diogo de Souza*, (*gobernador*)* e capitão general do Maranhão. [on line]<http://objdigital.bn.br/acervo_digital/div_manuscritos/mssI12_2_011.pdf> [March 2013].

Chaves, S.A.M. & K.J. Reinhardt. 2006. Critical analysis of coprolite evidence of medicinal plant use, Piauí, Brazil. Palaeogeography, Palaeoclimatology, Palaeoecology 237:110–118.

Chazdon, R.L. 2008. Chance and determinism in tropical forest succession. *In*: W.P. Carson & S.A. Schnitzer (ed.). Tropical Forest Community Ecology. Wiley-Blackwell, Chichester, West Sussex, UK. pp. 384-408.

Clinebell, R.R., O.L. Phillips, A.H. Gentry, N. Stark & H. Zuuring. 1995. Predictions of Neotropical tree and liana species richness from soil and climatic data. Biodiversity and Conservation 4:56–90.

Condit, R. 1995. Research in large, long-term tropical forest plots. Trends in Ecology and Evolution 10:18-22.

Condit, R. 1998. Ecological implications of changes in drought patterns: shifts in forest composition in Panama. Climatic Change 39:413-427.

Connell, J.H. 1990. "Apparent" versus "real" competition in plants. *In*: J.B. Grace & D. Tillman (eds.). Perspectives on Plant Competition. Academic Press, San Diego, California, U.S.A. pp. 9-26.

Connell, J.H. & R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. The American Naturalist 111:1119-1144.

Corona, P. & M. Marchetti. 1998. Towards an effective integration of forest inventories and natural resources surveys: the Italian perspective. *In*: M. Hansen & T. Burk (eds.). Integrated tools for natural resources inventories in the 21st century. U.S. Department of Agriculture. pp. 28-34.

Cramer, V.A., R.J. Hobbs & R.J. Standish. 2008. What's new about old fields? Land abandonment and ecosystem assembly. Trends in Ecology and Evolution 23:104-112.

Crutzen, P.J. & E.F. Stoermer. 2000. The "anthropocene". Global Change Newsletter 41:17-18.

de Landa, D. 1556. Relación de las cosas de Yucatán. [on line] <http://www.wayeb.org/download/resources/landa.pdf> [March 2013].

de Medeiros, P.M., A.L.S. de Almeida, R.F.P. de Lucena, F.J.B. Souto & U.P. de Albuquerque.

2010. Uso de estímulos visuais na pesquisa etnobiológica. *In*: U.P. de Albuquerque, R.F.P. de Lucena & L.V.F.C. de Cunha (eds.). Métodos e técnicas na pesquisa etnobiológica e etnoecológica. NUPEEA. Recife, Pernambuco, Brazil. pp. 151-170.

de Mello, F.P. 2004. Guerreiros do Sol – Violência e banditismo no Nordeste do Brasil. Girafa. SaoPaulo, Sao Paulo, Brazil. A Girafa. 512 p.

Denslow, J.S. 1987. Tropical rainforests gaps and tree species diversity. Annual Review of Ecology and Systematics 18:431-451.

Diggs, I. 1940-1956. Zumbi and the Republic of Os Palmares. Phylon 14:62-70.

Engelbrecht, B.M.J., L.S. Comita, R. Condit, T.A. Kursar, M.T. Tyree, B.L. Turner & S.P. Hubbell. 2007. Drought sensitivity shapes species distribution patterns in tropical forests. Nature 447:80-83.

Falola, T. & M. Heaton. 2008. A history of Nigeria. Cambridge University Press. Cambridge, UK. 329 p.

Fausto, B. 1999. A concise history of Brazil. Cambridge University Press. Cambridge, UK. 362 p.

Garrido-Pérez, E.I. & G. Gerold. 2009. Land-use history and the origins and effects of lianas on tree communities. Erdkunde 63:211-227.

Gasteazoro, C.M., C.A. Araúz & A.M. Pinzón. 1980. La historia de Panamá en sus textos. Tomo I (1501-1903).

Editorial Universitaria. Panama, Panama, Panama. 385 p.

Gerhardinger, L.C., E.A. Godoy, C.G. Dapper, R. Campos, G.B Marchioro, R. Sforza & M. Polette. 2010. Mapeamento participativo da paisagem marinha no Brasil experiencias e perspectivas. *In*: U.P. Albuquerque, R.F.P. de Lucena & L.V.F.C. de Cunha LVFC (eds.). Métodos e técnicas na pesquisa etnobiológica e etnoecológica. NUPEEA. Recife, Pernambuco, Brasil. pp. 109-149.

Goldberger, A.S. 1972. Structural equation models in the social sciences. Econometrica 40:979-99.

Grace, J.B. & B.H. Pugsek. 1997. A structural equation model of plant species richness and its application to a coastal wetland. The American Naturalist 149:436-460.

Guariguata, M.R. & R. Ostertag. 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. Forest Ecology and Management 148:185-206.

Herrera, D.A. 1752. Aviso histórico, político, geographico, con las noticias más particulares del Perú, Tierra-Firme, Chile y Nuevo Reyno de Granada. [online] <http://books.google.de/books?id=ciCHGwAACAAJ&dq=aviso+historico,+politico+y+gegrafico&hl=es-419&sa=X&ei=Q66rUI-RBszMsgaj24DwAw&ved=0CCkQ6AEwAA> [March 2013].

Homann, J.B. 1714. Tabula Ducatus Carniolia, Vindorum Marchia et Histria ex mente Illustr.mi quondam L.B. Valvasorii. Digital Library of Slovenia (mapnumber H0A6U2FA). [on line]. <http://www.dlib.si/results/?query='keywords%3dH0A6U2FA' & page Size=25> [March 2013].

Hope, D., C. Gries, W. Zhu, W.F. Fagan, C.L. Redman, N.B. Grimm, A.L. Nelson, C. Martin & A. Kinzig. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Science 100:8788-8792.

Hubbell, S.P. 2001. The Unified Neutral Theory of biodiversity and Biogeography. Princeton University Press. Princeton, New Jersey, U.S.A. 448 p.

Hubbell, S.P. 2008. Approaching ecological complexity from the perspective of symmetric neutral theory. *In*: W.P. Carson & S.A. Schnitzer (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, Chichester, West Sussex, UK. pp. 143-159.

Kindermann, J.K. 1818. Charte von dem Konigreiche Illyrien *I*. Digital Library of Slovenia (map number W3Y5X59J). [on line]

<http://www.dlib . sresults/?query =' keywords%3dW3Y5X59J ' &page Size=25. Dates of posting and update unknown> [March 2013].

Kovac, M. & M. Hocevar. 2010. Short description on forest inventories and the control sampling method around the world and Slovenia. Studia Forestalia Slovenica Professional and Scientific Works 136:7-10.

Kozler, P. 1853. Zemljovid Slovenske Dezele. Digital Library of Slovenia (map number RKLLJ45G). [on line] <http://www.dlib.si/results/?query='keywords%3dRKLLJ45G'&pageSize=25> [March2013].

Leal, I.R., A. Vicente & M. Tabarelli. 2003. Herbivoria por caprinos na caatinga: uma estimativa Preliminar. *In*: I.R. Leal, M. Tabarelli & J.M.C. Silva. (eds.). Ecologia e conservação da caatinga. Editora Universitária, Universidade Federal de Pernambuco. Recife, Pernambuco, Brazil. pp. 695-715.

Lensink, A. 2008. The health and nutrition strategies of enslaved Africans in Jamaican

sugar plantations. Time Pieces 9:35-48.
Macaulay, N. 1978. The Cuban rebel army: a numerical survey. The Hispanic American Historical Review 58:284-295.
Mamede, M.A. & F.S. Araújo. 2008. Effects of slash and burn practices on a soil seed bank of caatinga vegetation in northeastern Brazil. Journal of Arid Environments 72:458-470.
Martínez-Ramos, M. 1994. Regeneración natural y diversidad de especies arbóreas en selvas húmedas. Boletín de la Sociedad Botánica de México 54:179-224.
Matlack, G.R. 1997. Four centuries of forest clearance and regeneration in the hinterland of a large city. Journal of Biogeography 24:281-295.
MacCallum, R.C. & J.T. Austin. 2000. Applications of structural equation modeling in psychological research. Annual Review of Psychology 51:201-226.
McGill, B.J., B.A. Maurer & M.D. Weiser. 2006. Empirical evaluation of neutral theory. Ecology 87:1411-1423.
Moles, A.T. & M. Westoby. 2004. What do seedlings die from and what are the implications for evolution of seed size? Oikos 106:193-199.
Montanus, P. 1605. Brasilia, Cart 98488. Biblioteca Digital del Patrimonio Iberoamericano. [on line] http://objdigital.bn.br/acervo_digital/div_cartografia/cart984883.jpg [March 2013].
Naveh, Z. & R.H. Whittaker. 1979. Structural and floristic diversity of shrublands and woodlands in northern Israel and other Mediterranean areas. Vegetatio 41:171-190.
Neto, L. 2009. Padre Cícero –poder, fé e guerra no sertão. Companhía das Letras. Sao Paulo, São Paulo, Brazil. 560 p.
Petek, F. & M. Urbanc. 2004. The Franziscean land cadastre as a key to understanding the 19th century cultural landscape in Slovenia. Acta Geographica Slovenica 44:89-113.
Phillips, O.L. & J.S. Miller. 2002. Global patterns of plant diversity: Alwyn H. Gentry's forest transect data set. Missouri Botanical Garden Press. St. Louis, Missouri, U.S.A. 319 p.
Phillips, O.L., R.V. Martínez, P.N. Vargas, A.L. Monteagudo, M.C. Zans, W.G. Sánchez, A.P. Cruz, M. Timana, M. Yli-Halla & S. Rose. 2003. Efficient plot based floristic assessment of tropical forests. Journal of Tropical Ecology 19:629–645.
Pinto, J.S. 1813. Mapa topografico em que se mostrao as terras que fo no dos reverendos congregados, desde a Barra do Bituri pelo Rio Ipajuca a sima, ate as suas nascencas e do posso furido pelo Rio Capibaribe a sima te Alagoa do Angu, em as quaes se echao a comprendridas os sitios da madre de D Joao, inhumas, e outros como abaxo se demonstra.[on line] <http://upload.wikimedia.org/wikipedia/commons/8/8f/Ororub%C3%A1_oratorianos_Cart515170.jpg> [March 2013].
Pouyat, R.V., I.D. Yesilonis, K. Szlavecz, C. Csuzdi, E. Hornung, Z. Korsós, J. Russell-Anelli & V. Giorgio. 2008. Response of forest soil properties to urbanization gradients in three metropolitan areas. Landscape Ecology 23:1187–1203.
Poore, M.E.D. 1955. The use of phytosociological methods in ecological investigations I. The Braun-Blanquet system. Journal of Ecology 43:226-244.
Reed, N.A. 1964. The caste war of Yucatan. Stanford University Press. Stanford, California, U.S.A. 448 p.
Ribas, A.R.E. 2009. La derrota de la fuerza de maniobra de Cataluña. Revista de Historia Militar 106:63-99.
Rosindell, J., S.P. Hubbell & R.S. Etienne. 2011. The unified neutral theory of biodiversity and biogeography at age ten. Trends in Ecology and Evolution 26:340-348.
Sampaio, E.V.S.B., E.L. Araújo, I.H. Salcedo & H. Tiessen. 1998. Regeneração de caatinga após corte e queima, em Serra Talhada, PE. Pesquisa Agropecuária Brasileira 33:621-632.
Sampaio E.V.S.B., I.H. Salcedo & J.B. Kauffman. 1993. Effect of different fire severities on coppicing of caatinga vegetation in Serra Talhada, PE, Brazil. Biotropica 25:452-460.
Santos, A.M. & M. Tabarelli. 2002. Distance from roads and cities as a predictor of habitat loss and fragmentation in the caatinga vegetation of Brazil. Brazilian Journal of Biology 62:897 905.
Schnitzer, S.A. & F. Bongers. 2002. The ecology of lianas and their role in forests. Trends in Ecology and Evolution 17:223-230.
Shugart, H.H., T.M. Smith & W.M. Post. 1992. The potential for application of individual-based simulation models for assessing the effects of global change. Annual Review of Ecology and Systematics 23:15-38.
Šilc, U. 2006. Slovenian phytosociology in a database: state of the art, basic statistics and perspectives. Hladnikia 19:27-34.
Tscharntke, T., A.M. Klein, A. Kruess, I. Steffan-

Dewenter & C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8:857-874.

Teixeira, F.M.P. 1993. Historia concisa do Brasil. Global. Sao Paulo, Sao Paulo, Brazil. 514 p.

Tobler, W. 1970. A computer movie simulating urban growth in the Detroit region. Economic Geography 46:234-40.

Toledo, V.M., B, Ortíz-Espejel, L. Cortés, P. Moguel & M.J. Ordoñez. 2003. The multiple use of tropical forests by indigenous peoples in Mexico: a case of adaptive management. Conservation Ecology 7:9. URL: http://www.consecol.org/vol7/iss3/art9

Traas, A.G. 2010. Engineers at war. Center of Military History United States Army. Washington D.C., U.S.A. 647 p.

van der Aa, P. 1729. Le Bresil: suivant les nouvelles observations de messrs, Cart 163395. Biblioteca Digital del Patrimonio Iberoamericano. [on line] < http://objdigital.bn.br/acervo_digital/div_cartografia/cart163395.jpg> [March 2013].

van der Heijden, G.M.F. & O.L. Phillips. 2009. Environmental effects on neotropical liana species richness. Journal of Biogeography 36:1561-1572.

Wear, D.N., M.G. Turner & R.J. Naiman. 1998. Land cover along an urban-rural gradient: implications for water quality. Ecological Applications 8:619-630.

Wheeler J.C. 1995. Evolution and present situation of the South American Camelidae. Biological Journal of the Linnean Society 54:271-295.

Wright S.J. 2002. Plant diversity in tropical forests: a review of mechanisms of species coexistence. Oecologia 130:1-14.

Zamora, R., P. García-Fayos & L. Gómez-Aparicio. 2004. Las interacciones planta-planta y planta animal en el contexto de la sucesión ecológica. *In*: F. Valladares (ed.). Ecología del bosque mediterráneo en un mundo cambiante. Ministerio de Medio Ambiente, EGRAF SA. Madrid, Castilla-La Mancha, Spain. pp. 371-393.

Zeder, M.A. 2008. Domestication and early agriculture in the Mediterranean basin: origins, diffusion and impact. Proceedings of the National Academy of Science 105:11597-11604.