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REPORT

Multiple-factor classification of a human-modified forest landscape in the Hsuehshan Mountain Range, Taiwan

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Abstract Human actions drive landscape heterogeneity, yet most ecosystem classifications omit the role of human influence. This study explores land use history to inform a classification of forestland of the Tayal Mrqwang indigenous people of Taiwan. Our objectives were to determine the extent to which human action drives landscape heterogeneity. We used interviews, field sampling, and multivariate analysis to relate vegetation patterns to environmental gradients and human modification across 76 sites. We identified eleven forest classes. In total, around 70 % of plots were at lower elevations and had a history of shifting cultivation, terrace farming, and settlement that resulted in alder, laurel, oak, pine, and bamboo stands. Higher elevation mixed conifer forests were least disturbed. Arboriculture and selective harvesting were drivers of other conspicuous forest patterns. The findings show that past land uses play a key role in shaping forests, which is important to consider when setting targets to guide forest management.

Keywords Community classification · Nonmetric multidimensional scaling · Landscape history · Local knowledge · Tayal Mrqwang indigenous people · Smangus village

Abbreviations

EBLF	Evergreen broad-leaved forest
KMT	Kuomintang government
DBH	Diameter at breast height
LAI	Leaf area index
TRMI	Topographic relative moisture index
IMV	Importance value
NMS	Nonmetric multidimensional scaling
MRPP	Multi-response permutation procedure
ISA	Indicator species analysis
V	Vegetation type

INTRODUCTION

Many of the world's forests are shaped by past human activities. In many regions, secondary forests make up a large extent of present forest area, having developed on lands that were cleared in the past for agriculture, settlement, and resource extraction (Foster et al. 1998; Thompson et al. 2002; Bouchard and Pothier 2011). Even some areas considered to be "primary" or "natural" are recovering from episodes of forest clearing that occurred centuries and even millennia ago, the effects of which persist today (Willis et al. 2004). For instance, the composition of seemingly primary forest in Mexico is now linked to past use by Mayan farmers (Edwards 1986), and rain forests once presumed primary in Central Africa are now recognized as secondary following extensive former human occupation (van Gemerden et al. 2003). Influences of historical land use on forest structure and composition have also been documented in rainforests in Thailand (Kealhofer 2003), Nigeria (White and Oates 1999), the Amazon (Levis et al. 2012), and elsewhere (see Chazdon 2003).

There is growing awareness of the importance of considering human history in addition to environmental gradients in ecological studies of forest characteristics and trajectories. Understanding legacies of past land use can aid in the interpretation of forest heterogeneity, and they help

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to identify appropriate conservation and management targets (Foster et al. 2003). For instance, there are many places where past and ongoing practices of indigenous people have shaped forest patterns, and where maintenance of biodiversity requires continuation of traditional practices (Anderson and Posey 1989; Balée 1994; Junqueira et al. 2011). In such cases, conservation schemes that exclude humans from ecosystems may be counterproductive. Furthermore, they may impede cooperation between indigenous and non-indigenous stakeholders because they discount local history. Historical perspectives of forestland can help to identify practical management targets (Higgs et al. 2014) and facilitate dialog between land managers and local residents when planning for resource management and establishment of protected areas (e.g., Miller and Davidson-Hunt 2010).

Most studies on the effects of past land use have been carried out on landscapes that have been abandoned by people (e.g., Dambrine et al. 2007). Fewer studies have focused on landscapes that are currently inhabited by forest-dependent human populations. For these inhabited landscapes, data collected through a synthesis of quantitative and qualitative tools (e.g., plot sampling and interviews) can demonstrate how landscape pattern is shaped not only by historical actions, but also by the continuing activities of current descendants. For instance, Ellen (2007) describes how mature forests in Seram Indonesia reflect the influence of a variety of activities, which over hundreds of years has resulted in a higher density of certain plant species than forests would otherwise support. Other examples of such research include work from Africa (Fairhead and Leach 1995), India (Sahu et al. 2008), the Amazon (Balée 1994), and Indonesia (Peluso 1996).

In this study, we examine the history of human land use to assist in classifying forest types for an inhabited mountain landscape in the traditional territories of the Tayal Mrqwang indigenous people of Taiwan. Though it is widely acknowledged that indigenous peoples have lived in the island's mountain regions for thousands of years (Bird et al. 2004), this study is the first scientific classification of a forested landscape in Taiwan to include the influence of indigenous people. The study is unique in that it focuses at the fine scale, which is necessary to capture the patchiness of a human-modified landscape. Other published classifications that encompass our area of study are broad-scale vegetation-based systems (e.g., Hsieh et al. 1994; Chen 2001; Song et al. 2003; Song and Xu 2003; Li et al. 2013, 2015). Broad-scale classifications are important for understanding regional patterns, but they overlook the impact of land use legacies on spatial diversity and are thus inappropriate to guide restoration and management for forestland that has history of human activity.

We pursued two lines of questioning in this study: (1) What are the variables that are most useful for explaining forest distribution and diversity across the study area; and (2) To what extent does human action account for forest distribution and diversity? These questions were addressed by relating vegetation patterns in the study area to environmental gradients and interview data about current and ancestral human activities. The goal of the research was to provide insight on the influence and persistence of past human land use and thus contribute to a holistic understanding of forest heterogeneity. This knowledge is needed to identify appropriate targets for management of land and natural resources in mountain areas where local people continue to sustain a livelihood.

MATERIALS AND METHODS

Our approach to forest classification involved three key steps. The first step was plot sampling, which involved measurements of vegetation, physiography, soil, humidity, and light availability in 76 plots. The second step involved interviews with local Tayal people to determine land use history of sample plots. The third step was data analysis, which involved classification and ordination tools to relate vegetation patterns to environmental parameters and a disturbance gradient based on interview data. A final classification was developed by aligning sample plots into types according to similarities in physiography, soils, and vegetation. Land use history was used to contextualize the final classification by linking past land uses to the vegetation and soil patterns of forest types.

Study area

The study area is located in the montane region near Smangus village (24°34′41″N, 121°20′06″E, 1570 m a.s.l.) in the Hseuhshan mountain ranges and Tayal Mrqwang traditional territories, HsinChu County, Taiwan (Fig. 1). The site varies in elevation from 1450 m to 1800 m and extends across the predominantly south-facing slopes of Smangus mountain (2111 m), White Snow mountain (2444 m), and West Hill mountain (2427 m). Slopes are steep and highly dissected by erosion channels and narrow ridges. Parent materials of the region consist of Eocene and Oligocene quartzose, carbonate metasandstone, shale, slates, and argillites (Hsieh and Shen 1994). Major soil taxonomic categories include poorly developed entisols and general colluvium. There are also patches of localized human-modified soils that exist either as historically intensively farmed terrace soils with retaining walls or as occasionally cultivated soils on non-terraced slopes.

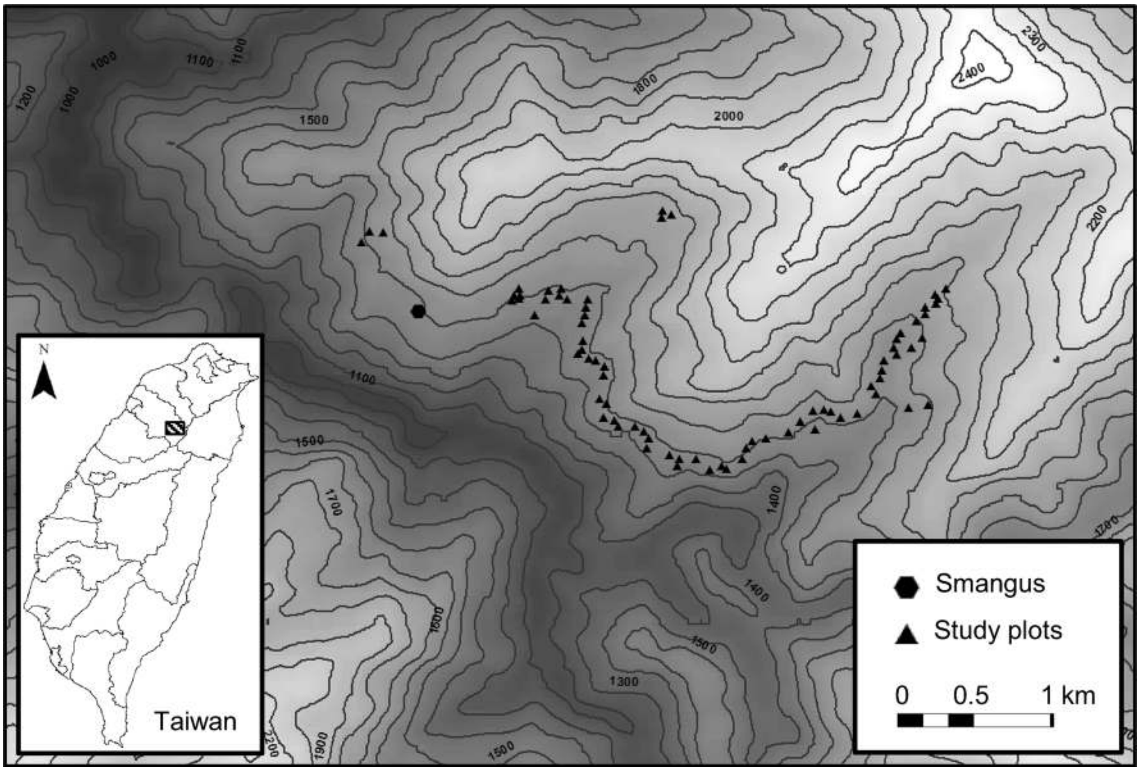

Fig. 1 Smangus village and the surrounding study area showing the locations of the 76 sample plots along the study transect

The study area is characterized by a warm-temperate moist climate. Mean monthly temperatures range from 14.2 to 27.5 °C, and mean annual precipitation is 1653 mm (Icyeh 2011). Rainfall occurs with highest intensity from June through September, and the area receives occasional snow in January. Major forest types grade between evergreen broad-leaved forest (EBLF) in the west and mixed coniferous forest in the east. There are also pockets of mixed red pine and bamboo forests that intergrade with EBLF on dry ridges and slopes.

Field sampling

Seventy-six plots were established along a midslope transect covering a distance of 10.4 km and bounded by upper and lower elevations of 1450 and 1800 m. Vegetation, geomorphology, soils, humidity, and light availability were measured at each plot between March of 2010 to June of 2011. The plots were randomly located at a minimum distance of 30 m from either side of footpaths on forested south-facing slopes (Fig. 1). The paths form a significant link in the ancestral Tayal migration route, and continue to serve as routes to various traditional hunting, gathering and fishing areas, agricultural fields, and sacred places, including former village sites and the village cemetery. The use of trails as transects was requested by village leadership because of the opportunity to collect educational information for village tourism (e.g., Icyeh 2011). The approach was also practical for the steep and often inaccessible terrain, providing access to a larger area than if we had located the transects randomly.

Vegetation in each plot was inventoried as trees (stems >5 cm Diameter at Breast Height (DBH), 1.3 m height), saplings and shrubs (<5 cm DBH, >1 m height), and ground flora (all vascular species <1 m in height). Trees were identified and measured for DBH within 10 m fixed radius quadrats, and canopy height was measured using a Haga altimeter. Saplings and shrubs were tallied for species frequency within 5 m fixed radius quadrats, and ground flora was measured within two 1 × 1 m quadrats using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). Species identification and nomenclature follows the Flora of Taiwan (Huang et al. 1994–2003). Voucher specimens were collected for all species and are stored in Smangus village and at the OAC Herbarium, University of Guelph.

Descriptions of geomorphology were made at plot centers, and followed Schoeneberger et al. (2002). We recorded elevation, slope aspect and gradient, and three categorical variables (plot surface slope shape, hillslope profile position, geomorphic component). Soils were sampled in each plot by exposing the vertical profile with a shovel, up to 100 cm in depth where possible. On bouldery and other impenetrable surfaces (e.g., bamboo forest floors), soils were sampled at trailcut exposures near the plot. Each discernible horizon was assessed for thickness, structure, consistence, rock fragments, roots, and soil color. Horizon samples were sieved and examined by feel for texture using the ribbon test. Sieved samples were analyzed for pH (1:5 soil:distilled water suspension, by volume) using a HannaTM pHep® 4 pH/Temperature Tester (HI 98127; Hanna Instruments, Ann Arbor, Michigan), following methods of Thomas (1996).

Temperature and humidity data were collected in each plot using a handheld LutronTM Humidity/Temp meter (LM-81HT; Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan). Data were collected by recording two-minute averages at each plot over the course of 5 h on an overcast afternoon on 19 May 2011. Plot-specific data were then scaled by subtracting plot averages from a baseline of simultaneous measurements recorded by a HOBO® Pro v2 RH/Temp Data Logger (Onset Computer Co., Pocasset, MA) installed in the village.

Light availability was measured at plot centers using hemispherical photography. We used a Sigma 4.5 mm F2.8 EX DC HSM 180° fisheye lens (Sigma Corporation, Kuriki) on a Nikon D90 body (Nikon Corporation, Tokyo), and the camera was leveled on a tripod in an upward-looking direction 1 m aboveground. A compass was used to orient the camera northward, and LED lights attached to the lens were used to indicate orientation for image analysis, following Frazer et al. (2001). Images were taken on overcast days to minimize error associated with light scattering (Gonsamo and Pellikka 2008), and exposure was set at two stops above the shutter speed measured in a nearby canopy gap. Pixel segmentation was completed using SideLook (version 1.1.01, ApplEco, www.appleco.ch) and pixel counts were extracted in Gap Light Analyzer (GLA) (version 2.0, www.caryinstitute.org). Of the various GLA output, we used canopy openness and leaf area index (LAI) in multivariate analyses.

Land use history

Information on land use history of the study area came from interviews with residents of Smangus village who belong to the Mrqwang subgroup of the Tayal tribe (also referred to as the Atayal). We conducted five group interviews with 12 village participants (aged 25 to 75 years old) using structured and semi-structured interview techniques as per Bernard (2002). Four of the older participants were interviewed independently. Interview topics included (i) place names, (ii) history and stories, (iii) past and current subsistence practices, (iv) plants and ecology, and (v) topography and soil. Interviews were transcribed and data from transcriptions were used (i) quantitatively to build an index of disturbance for use in multivariate analyses, and (ii) qualitatively to identify past human actions that are linked to current forest types.

Data conversion

Based on interviews and field observations, an index of disturbance was determined for each plot, integrating years since disturbance and intensity of disturbance (Table 1). Geomorphic variables were ranked by potential moisture availability (from dry to moist): (i) hillslope profile position (summit, shoulder, backslope, footslope, toeslope), and (ii) geomorphic component (crest, headslope, noseslope, sideslope, baseslope) (Wysocki et al. 2000). Plot surface shapes were assigned numerical values through the addition of across-slope and downslope integer grids coded as convex = 1 (dry), linear = 2, and concave = 3 (moist). A topographic relative moisture index (TRMI) was calculated following (Parker 1982). Aspect was transformed following (Beers et al. 1966). Munsell colors were transformed by multiplying hue by value following (Pitty 1978). Texture was converted to (i) percentages of sand, silt, and clay estimated from a texture triangle; and to (ii) an index of departure from a reference loam of 40% sand, 40% silt, and 20% clay. Importance values (IMV) were calculated for trees and saplings/shrubs as the average of relative dominance and relative density for each species on each plot. Importance values were also calculated for ground flora by averaging relative cover class and relative frequency for each species on each plot. See Berg (2013) for detailed explanations of all calculations.

Statistical analyses

Multifactor classification was developed using classification and ordination tools in PC-ORD (version 6.0, MjM Software Design, Gleneden Beach, OR). We constructed two matrices, including (i) a main matrix of species IMV data for trees, saplings and shrubs, and ground flora, and (ii) a secondary matrix with 34 environmental variables. Natural groupings of vegetation data were classified using cluster analysis (Flexible beta method, $\beta = -0.25$), and associations between species and relationships of species to environmental variables were evaluated through ordination with nonmetric multidimensional scaling (NMS) (Kruskal 1964). We used Sørensen's similarity coefficient (Bray and Curtis 1957) for both NMS and cluster analysis. NMS was run in autopilot mode at the slow and thorough setting, with preliminary ordinations cycled through 500 iterations at random initial configurations. To strengthen dominant community structure, we omitted very rare species (i.e.,

Table 1 Disturbance index values based on integrating years since disturbance and intensity of disturbance in sample plots along the study transect

Initial index value		Adjusted index value		
Years since disturbance	Index value	Disturbance intensity[b]		
		High	Medium	Low
Never disturbed	1	1	1	1
200 years	2	3	2	1
50–100 years	3	4	3	2
25–50 years	4	5	4	3
Recent[a] or current	5	5	5	5

[a] Within the last 10 years

[b] Examples of high intensity disturbance include shifting cultivation, terrace farming, and landslides; examples of low intensity disturbance include selective extraction, mushroom cultivation, trail building; and an example of medium intensity disturbance would be transition areas adjacent to the high intensity disturbances

species occurring in less than 5 % of plots) and deleted one outlying plot (plot 31; s.d. >2.0), reducing the matrix to 75 rows by 151 columns. We applied a square root transformation to columns to improve the coefficient of variation (CV) of species. Final dimensionality was determined as the number of axes beyond which reductions in stress were less than five units (McCune and Grace 2002). Solution stability was assessed with the final instability value, and the Monte Carlo test was used to ensure that a better-than-random configuration was achieved.

Differences between groups classified through cluster analysis were examined using multi-response permutation procedure (MRPP) (Mielke 1984) with Sørensen distances and rank-transformed distance matrices. Group differences detected by MRPP were then examined with indicator species analysis (ISA) (Dufrêne and Legendre 1997). This analysis combines proportional frequency with relative abundance to compute the value of each species for indicating each group (McCune and Grace 2002). ISA was also used to prune dendrograms, with the number of clusters selected at a level of information loss that generated the highest number of significant indicator species (Dufrêne and Legendre 1997; Peck 2010). Additional analyses comparing environment, structure, and diversity measures across forest types were completed using SAS JMP IN® ver. 10 (SAS Institute Inc., Cary, NC).

A final classification of site types was developed based on protocols described in Barnes et al. (1982) and Spies and Barnes (1985) in which sample plots were aligned according to similarities in physiography, soils, and vegetation. Initial approximations of the classification were based on the alignment of vegetation dendrograms with physiography and soil dendrograms derived from the environment matrix; plots belonging to similar vegetation clusters were defined as a site type if they also belonged to similar physiography and soil clusters. Alignment was then fine tuned using ordination to clarify relationships among plots and between plot groupings and environmental parameters. Combinations of physiography, soil, and vegetation were accepted as valid site types if they (i) recurred on the landscape, or were greater than 1 ha; (ii) were distinct in terms of diversity and mensuration; and (iii) were ecologically reasonable (Spies and Barnes 1985). Differences in vegetation between two plots (or two groups of plots) that were not accompanied by divergence in physiography or soil were attributed to natural variation or human modification within a site type.

RESULTS

Gradient analysis

A total of 246 species (Appendix S1) were identified across the 75 plots. Of these, six species were common, occurring in more than 50 % of plots, and 113 species were rare, occurring in less than 5% of plots. Seven communities were evident in cluster analysis by pruning the dendrogram at 27 % information remaining (ISA: $P = 0.1739$, IVmax = 3664) (Fig. 2). The seven groups were significantly different overall (MRPP: $T = -28.16$, $A = 0.68$, $P < 0.001$), and there were significant differences for all pairwise comparisons. NMS of the 75 plots resulted in a 3-dimensional solution that represented 80.8% of variation in the data (axis 1 = 18.0%, axis 2 = 47.8%, axis 3 = 14.9%), and had a final stress of 14.0 ($P = 0.0040$, 74 iterations, instability value $<10^{-5}$). The seven communities occupied distinct regions of ordination space and had minimal overlap (Fig. 3), with group dispersion correlating primarily to opposing gradients of elevation and disturbance along axis two (Table 2). Axis two also corresponded with humidity, canopy height, and thickness and

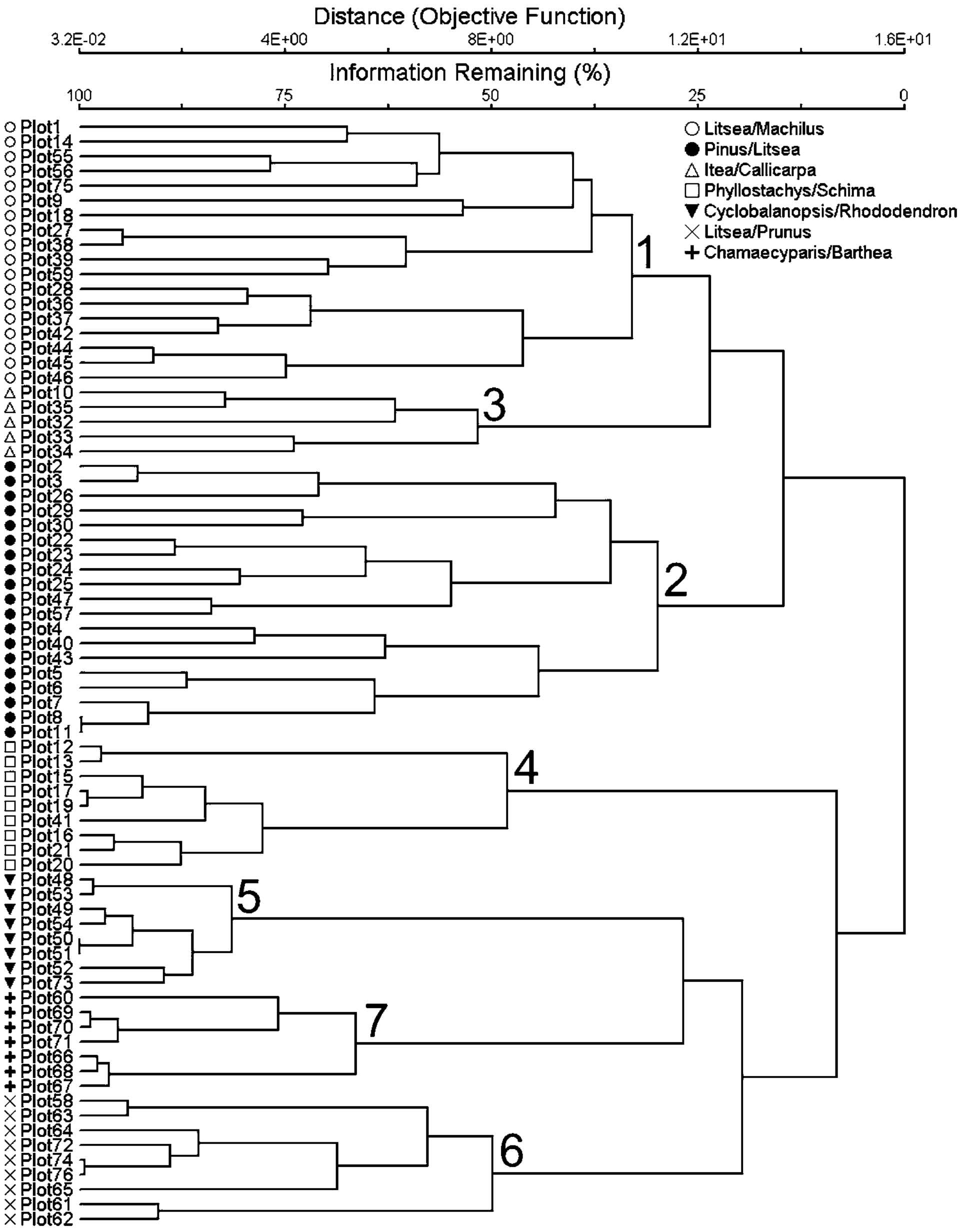

Fig. 2 Cluster analysis dendrogram of vegetation data for 75 plots along the study transect. Seven groups are distinguished by pruning the dendrogram at 27 % information remaining. Groups are identified in the legend by the genus names of their two most dominant species

texture of horizon A. Axis one was associated most strongly with structure and diversity parameters (i.e., tree density and DBH), while axis three was correlated most strongly with light availability (LAI; $\tau = +0.32$, $r^2 = 0.26$) and soil structure ($\tau = -0.42$, $r^2 = 0.33$).

Classification

We identified five ecosystem site types, as well as two provisional ecosystem site types (sites 4 and 6) that were represented by only 2 or 3 plots (Table 3, Appendix S2). The sites are named numerically (e.g., Site type 1), but are each further delineated by moisture and flora of their associated vegetation types (V). A hierarchical classification was devised consisting of 4 levels, with site types separated by elevation, physiography, soil, and vegetation. Elevation was used as the highest level because factors relating to altitude, such as temperature and moisture, are well documented as key determinants of vegetation zonation on mountain slopes in Taiwan (Hsieh et al. 1994, 1998; Li et al. 2013). Factors related to physiography and soils comprised the second and third levels because they are relatively stable compared to vegetation (Barnes et al. 1982).

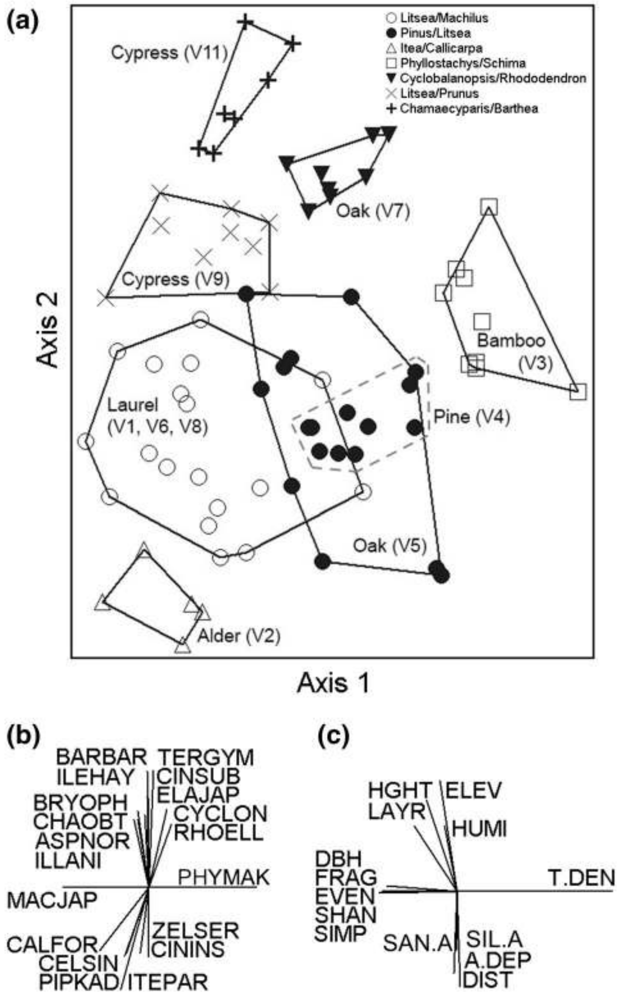

Fig. 3 Nonmetric multidimensional scaling (NMS) ordination of 75 plots based on the importance values of 151 species occurring along the study transect (**a**). Symbols and encircling convex hulls indicate plot groupings identified through cluster analysis. Groups are described in the legend by the genera of the two most dominant species. Labels that accompany each cluster within the figure represent vegetation types (V) delineated through the classification in Table 3. Environment vectors (**c**) have $r^2 \geq 0.200$. Species vectors (**b**) have $r^2 \geq 0.250$. Refer to Table 2 for environment and species vector codes

We distinguished 11 vegetation types across the five ecosystem site types. General vegetation patterns at the low elevations ranged from laurel, alder, and bamboo forests in site 1, to red pine in site 2, and oak in site 3 (Table 3; Fig. 3, Appendices S3–S4). Vegetation at the upper elevation zone ranged from oak, laurel, and Formosan cypress forests in site 5, to oak in site 6, and Hinoki cypress in site 7. Species richness was highest in the cypress vegetation types (V9, V11) and oak (V5), and lowest in bamboo (V3) (Table 4). The cypress (V9, V11) and oak (V5, V7) forests had the greatest basal area and stem DBH, whereas bamboo (V3) had the greatest stem density. The lowest stem density was in cypress and alder (V2). Canopy openness was lowest in cypress and laurel (V1), and highest in red pine (V4) and oak. Canopy height was lowest in bamboo, and humidity was lowest in red pine; both indices were at their highest in cypress. The index of disturbance was lowest in cypress and highest in alder.

Land use history

The Tayal Mrqwang people settled in the area near Smangus village over 200 years ago and they fostered a subsistence livelihood characterized by shifting cultivation, hunting and gathering, and fishing. The area was abandoned in 1926 when Japanese administrators resettled villagers to lower-lying foothills and the area was uninhabited for the next 20 years until after Japan's defeat in the Pacific War (Icyeh 2011). Returning residents practiced subsistence activities but later turned to semi-permanent agriculture when the Kuomintang (KMT) government prohibited unregistered subsistence activities in the late 1960s. Since then, intensive agricultural activities have mainly occurred within designated reserve zones near the village, though many residents continue to utilize forest resources for at least part of their household requirements.

With the exception of the cypress stands, much of the study area has been influenced by the Tayal people over past centuries, with signs of past land use exhibited in 58 of 76 plots and 8 of 11 forest types. Much of this activity occurs in the low to mid elevation zone due to the unsuitability for agriculture at higher elevations, resulting in the inverse relationship between elevation and disturbance (Fig. 3). There are also abundant surface and material traces of past land use throughout the survey area, including (i) ruins of stonewalled terraces (Fig. 4a, c), house foundations, and storage cellars; (ii) depressions of old hunting trails, camps, and irrigation canals; and (iii) culturally modified trees.

DISCUSSION

There is growing recognition that many present-day forests are shaped by past human activity in addition to environmental gradients (Foster et al. 2003). Some studies show that the effects of past land use can persist for decades (even centuries) and override environmental influences (Thompson et al. 2002; Dambrine et al. 2007). Our research shows that vegetation in the study area is distributed primarily along gradients of elevation, soil, humidity, and human modification, and that predominant vegetation types within low to mid elevations coincide with years since disturbance and type of disturbance. Below we summarize general vegetation and soil patterns in the study area relative to other mountain forests in Taiwan and examine the imprint

Table 2 List of correlation values for environmental parameters (|τ| and $r^2 \geq 0.200$) and species (|τ| and $r^2 \geq 0.250$) that were associated with ordination axes 1 and 2 for the NMS of plots along the study transect

Environmental parameters	Code	Axis	τ	R^2
A horizon thickness	A.DEP	2	−0.37	0.23
A horizon % sand	SAN.A	2	−0.35	0.20
A horizon % silt	SIL.A	2	−0.34	0.21
Canopy height	HGHT	2	+0.44	0.36
Disturbance	DIST	2	−0.51	0.38
Elevation	ELEV	2	+0.47	0.44
Evenness	EVEN	1	−0.28	0.31
Humidity	HUMI	2	+0.37	0.26
Number of canopy layers	LAYR	2	+0.36	0.26
Shannon's index	SHAN	1	−0.23	0.27
Simpson's index	SIMP	1	−0.23	0.30
Stem (tree) DBH	DBH	1	−0.36	0.28
Stem (tree) density	T.DEN	1	+0.55	0.62
Surface fragments	FRAG	1	−0.34	0.22
Species	Code	Axis	τ	R^2
Asplenium normale	ASPNOR	2	+0.40	0.27
Barthea barthei	BARBAR	2	+0.53	0.46
Callicarpa formosana	CALFOR	2	−0.39	0.25
Celtis sinensis	CELSIN	2	−0.45	0.27
Chamaecyparis obtusa	CHAOBT	2	+0.42	0.29
Cinnamomum insulari-montanum	CININS	2	−0.46	0.28
Cinnamomum subavenium	CINSUB	2	+0.50	0.35
Cyclobalanopsis longinux	CYCLON	2	+0.50	0.31
Elaeocarpus japonicus	ELAJAP	2	+0.46	0.33
Ilex hayataiana	ILEHAY	2	+0.52	0.36
Illicium anisatum	ILLANI	2	+0.40	0.27
Itea parviflora	ITEPAR	2	−0.48	0.41
Machilus japonica	MACJAP	1	−0.46	0.34
Bryophytes	BRYOPH	2	+0.41	0.31
Piper kadsura	PIPKAD	2	−0.41	0.27
Rhododendron ellipticum	RHOELL	2	+0.38	0.25
Ternstroemia gymnanthera	TERGYM	2	+0.57	0.47
Zelkova serrata	ZELSER	2	−0.44	0.26
Phyllostachys makinoi	PHYMAK	1	+0.47	0.43

on vegetation and soil of four general land uses, including (i) shifting cultivation, (ii) terrace farming, (iii) settlement, and (iv) arboriculture and extraction.

General patterns in vegetation and soils

Of the eleven forest types identified in this study, three are common secondary forest types (pine, bamboo, and alder; V2–V4) and eight are characteristic of EBLF and mixed coniferous forests specified by Hsieh et al. (1994) and Li et al. (2013) as being endemic to the area (V1, V5–V11). Based on interviews, however, five of the eight endemic forests (V1, V5–V8) have been cultivated in the past and have since assumed the structure and composition of endemic types. This means that eight of the eleven forest types are secondary, all occurring at low to mid elevations (Table 3). The upper elevation forests have remained relatively undisturbed and consist mainly of mixed cypress stands characterized by large *Chamaecyparis* trees that reach heights of 40 m and 100–200 cm DBH.

Table 3 Site types and general descriptions of associated vegetation types at low, middle, and high elevation ranges along the study transect. Vegetation type names reflect moisture status, overstory, and understory dominants (separated by a hyphen), and the strongest indicator species, if present. See Appendix S2 for the detailed forest classification and complete descriptions of each site and vegetation type

Elevation (m)	Site type	Vegetation type (V)	Average disturbance index
1492–1620	1	V1. Submesic laurel–*Arachniodes*: Tall EBLF stands with medium to heavy canopy cover; formerly cultivated	3
		V2. Submesic alder–*Miscanthus/Rubus taitoensis*: Low-statured and patchy EBLF stands with partially exposed canopy cover; recently cultivated	4.2
		V3. Submesic bamboo–*Parthenocissus*: Dense bamboo stands with low canopy openness; former village sites	2
	2	V4. Xeric red pine–*Miscanthus/Carpinus kawakamii*: Mixed red pine and EBLF stands with open canopy cover; former terraced fields	4
	3	V5. Xeric oak–*Hydrangea/Ficus erecta*: Tall EBLF stands with medium canopy cover; formerly cultivated in some areas	2.6
	4	V6. Submesic laurel–*Maesa*: Low-statured EBLF stands with low canopy cover; history of cultivation or selective harvesting in some areas	2
1620–1690	5	V7. Submesic oak–*Plagiogyria/Lasianthus japonica*: Tall mixed conifer and EBLF with patchy cover; history of disturbance in some plots	2.5
		V8. Mesic laurel–*Diplazium/Maesa perlaria*: Tall EBLF with medium to heavy cover; history of disturbance in some plots	2.5
		V9. Mesic Formosan cypress–*Arachniodes/Arachniodes pseudo-aristata*: Very tall mixed conifer and EBLF stands with low canopy openness	1
1690–1780	6	V10. Mesic oak–*Prunus/Viburnum odoratissimum*: Very tall EBLF stands with medium canopy cover	1
	7	V11. Mesic Hinoki cypress–bryophytes/*Asplenium tenuicaule*: Very tall mixed conifer and EBLF stands with low to medium canopy openness	1.1

Soils of the study area have been classified broadly as entisols (Sheh and Wang 1991), but our data demonstrate a gradient from high elevation podzols to variably developed entisols and anthropic soils at low to mid elevations. The Tayal people distinguish the low to mid elevation soils by the terms “m’hagay,” denoting weathered, loose, and stony substrate that deteriorates when exposed to the sun, and “ksumux,” meaning rich soil that is good for agriculture. Ksumux soils occur in sites 4, 2, and 1 and feature a distinct topsoil layer with pronounced subsurface horizon development. The highest degree of horizonation occurs in the alder forest (V2) of site 1, which is the forest type with the most recent history of cultivation. The alder soils have a coarser structure and texture compared to poorly developed and granular entisols of adjacent forests at more advanced successional stages (e.g., V1, V5, V6). These patterns are indicative of cropping effects and other anthropedogenic processes resulting from long-continued cultivation (USDA 1999).

Shifting cultivation

Shifting cultivation has left a persistent imprint on forestland at low to mid elevations in the study area. The type of shifting cultivation practiced by the Tayal people was a small-scale long forest-fallow form, where stands were cleared, burned, and cultivated on a rotating ~20-year cycle, and soil was lightly prepared with hand tools. This practice has impacted 55 of 76 plots (including parts of V1–V8) and resulting vegetation in these areas demonstrates wide-ranging succession. The areas that were cultivated most recently (40–50 years ago) are alder forests (V2, Fig. 4b), characterized by well-developed soils and low-statured deciduous cover dominated by alder trees (*Alnus formosana*). Alder is a common nitrogen-fixing pioneer of disturbed lands in Taiwan (Yang et al. 2010), and its presence indicates forest recovery from past disturbance, such as cultivation. However, alder forests are also indicative of large-scale arboriculture: elders explained that ancestors would intentionally sow alder seeds on newly abandoned lands, and when they returned years later, the mature alder trees would be cut, burned, and incorporated into soils as fertilizer prior to cropping.

The imprint of shifting cultivation is also evident in forestland that was cultivated over a century ago. The laurel–*Maesa* forest type (V6) occurs adjacent to alder forests on hillslope land that was cultivated and left fallow by Tayal ancestors between 100 to 200 years ago. The site contains abundant evidence of past use, including collapsed stonewalls that are partially buried through advanced slope

Table 4 Means (± s.e.) of select site characteristics for the eight vegetation types along the study transect that have a sample size greater than three. See Berg (2013) for additional site parameters, and for measurements of the remaining three vegetation types (V6, 8, 10)

Site type	1			2	3	5		7
Vegetation type	1	2	3	4	5	7	9	11
Number of plots (n)	7	5	7	7	7	6	7	6
Elevation range (m)	1545–1578	1492–1589	1540–1568	1495–1627	1537–1576	1625–1643	1628–1669	1693–1780
Species richness	23.14 (1.12)	23.60 (1.94)	15.86 (1.16)	29.29 (2.20)	32.14 (4.04)	26.00 (3.83)	30.14 (1.74)	32.50 (1.80)
Humidity index	−6.56 (1.16)	−9.91 (1.85)	−4.59 (0.48)	−10.64 (0.97)	−3.71 (0.59)	−3.88 (0.83)	1.72 (0.96)	0.51 (0.66)
Canopy openness index	3.06 (0.35)	4.10 (0.44)	3.33 (0.42)	6.32 (1.06)	4.34 (0.97)	4.71 (0.49)	2.99 (0.31)	3.05 (0.26)
Leaf area index (LAI)	3.98 (0.23)	3.43 (0.17)	3.93 (0.21)	3.07 (0.25)	3.56 (0.21)	3.33 (0.13)	3.97 (0.14)	3.91 (0.12)
Canopy height (m)	25.00 (1.89)	23.00 (2.55)	20.71 (3.52)	25.14 (1.89)	27.14 (2.14)	31.67 (1.67)	40.71 (0.71)	40.00 (0)
Basal area ($m^2 \cdot ha^{-1}$)	53.81 (7.90)	42.66 (7.57)	82.72 (17.10)	70.30 (10.33)	163.58 (90.07)	62.98 (8.02)	148.64 (41.96)	115.74 (20.54)
Stem DBH (cm)	14.33 (1.29)	16.72 (2.50)	6.57 (0.23)	13.29 (0.74)	18.50 (2.47)	15.23 (1.05)	21.89 (2.37)	18.59 (1.50)
Stem density (per ha)	2750 (1007)	1458 (259)	16 680 (1041)	3033 (366)	2292 (301)	2026 (155)	1241 (110)	1570 (144)
Sapling density (per ha)	3383 (449)	2037 (516)	2364 (323)	5438 (1011)	4947 (535)	8317 (1586)	4365 (450)	5177 (728)
Disturbance index	3.00 (0.35)	4.20 (0.38)	2.00 (0)	4.00 (0.43)	2.57 (0.20)	2.50 (0.22)	1.00 (0)	1.14 (0.16)
Slope (degrees)	36.43 (4.85)	35.50 (2.79)	32.86 (3.16)	30.71 (3.17)	44.64 (2.59)	41.67 (2.39)	31.07 (4.75)	32.08 (3.89)
TRMI	40.24 (2.79)	33.00 (1.33)	36.91 (3.08)	30.48 (1.77)	30.00 (1.50)	31.67 (3.55)	42.14 (4.94)	36.39 (2.77)
Thickness O horizon (cm)	1.64 (0.98)	0.33 (0.17)	–	5.86 (1.53)	0.93 (0.70)	7.17 (3.17)	5.36 (2.26)	30.0 (–)
A horizon								
Thickness (cm)	19.86 (4.18)	14.33 (8.68)	13.00 (3.49)	0.60 (0.51)	16.71 (7.82)	–	3.29 (2.36)	–
% Silt	47.14 (4.61)	40.00 (0)	42.50 (2.50)	–	35.00 (3.27)	–	11.43 (7.97)	–
% Sand	34.29 (3.69)	40.00 (0)	35.00 (5.00)	–	40.71 (4.93)	–	11.43 (7.97)	–
% Clay	18.57 (0.92)	20.00 (0)	22.50 (2.50)	–	24.29 (6.12)	–	5.71 (3.98)	–
B horizon								
Thickness (cm)	41.86 (9.34)	19.00 (1.00)	24.50 (3.28)	18.14 (2.62)	25.14 (4.92)	24.80 (7.61)	13.14 (5.09)	5.0 (–)
% Silt	44.29 (6.02)	41.00 (1.29)	43.33 (6.15)	40.71 (1.70)	34.29 (3.69)	38.00 (8.74)	37.86 (1.09)	15.0 (–)
% Sand	30.71 (3.85)	34.00 (7.75)	29.17 (4.17)	37.14 (3.42)	34.29 (3.69)	39.00 (5.57)	41.43 (2.82)	65.0 (–)
% Clay	25.00 (5.98)	25.00 (6.45)	27.50 (6.55)	22.14 (1.84)	31.43 (7.34)	23.00 (3.39)	20.71 (2.75)	20.0 (–)
Soil pH	5.69 (0.16)	5.22 (0.11)	5.42 (0.15)	5.09 (0.14)	5.23 (0.17)	5.16 (0.11)	4.56 (0.14)	3.81 (–)

Fig. 4 Examples of different forest features shaped by human activity: **a** Terrace ruins in V6 submesic laurel–*Arachniodes* (*upper left*); **b** Alder forest in V2 submesic alder–*Miscanthus* (*upper right*); **c** Terrace ruins in V4 xeric pine–*Miscanthus* (*lower left*); **d** soil profile in V4 xeric pine–*Miscanthus* (*lower right*)

movement (Fig. 4a). The plant community demonstrates successional replacement of alder forests. For instance, laurel–*Maesa* forests are similar to the alder forests in height, openness, basal area, stem DBH, and density, and in the overstory abundance of *Alnus formosana*, but the dominant overstory and understory tree is *Litsea acuminata*, indicating advanced replacement by EBLF species (Chiou et al. 2009; Yang et al. 2010). Soil profiles of laurel–*Maesa* demonstrate similar indications of time since disturbance: boundary layers among horizons are diffuse; soils have less defined structure; and there is reduced silt content.

Terrace farming

Terrace farming is more intensive than shifting cultivation, involving not only forest clearing, but also soil excavation and construction of rock walls. This type of sedentary cultivation was imposed on the Tayal people during Japanese and early KMT rule as it enabled governments to maintain better control of forest resources. The practice was used to varying degrees across the study area, but it was practiced most intensively on a broad hillslope area near the village. This area was abandoned due to village resettlement in 1926 and again in 1968 following initiation of a reserve land system, whereupon villagers were prohibited from cultivating outside of reserve boundaries. The area is steep and rocky, but due to prior cultivation, most soils on terrace beds and surrounding hillsides are well developed, with deep O layers, clear horizonation, and rich subsurface loams (Fig. 4d). The area has transitioned primarily to xeric *Pinus* forests (V4, Fig. 3), which are a common post-disturbance forest type in Taiwan (Chiou et al. 2009).

Settlement

Two former village sites occur along the transect, and vegetation of the sites corresponds with the bamboo forest type (V3) of which *Phyllostachys makinoi* (Makino bamboo) is the primary species. The sites were inhabited between 100 and 200 years ago and they contain numerous ruins of rock foundations and walls. Villagers state that bamboo is "a gift from our ancestors" (Icyeh 2011) and that most of the bamboo forests in the area represent villages and agricultural areas of their ancestors. Bamboo biology corroborates this history, as bamboo reproduces primarily through rhizomes (Yen et al. 2010), making it an unlikely pioneer of abandoned lands unless already growing in an adjacent space, or unless introduced by cuttings. The two village sites are geographically disconnected, suggesting that the growth of bamboo was a result of propagation by settlers. The overstory of the bamboo forests confirms a history of settlement. The second most dominant species in the bamboo forests is *Schima superba,* which is a common pioneer of disturbed environments, but has poor capacity to regenerate in the low light of established forests (Song et al. 2011). These traits ensure that *S. superba* is common in early to mid-successional forests, but is absent in the understory, which is consistent with this study, and reflects a post-disturbance community shifting towards the replacement of *S. superba.*

Arboriculture and extraction

Across the study area, the tending and harvesting of valued species over hundreds of years has resulted in conspicuous patterns in stem density of fruit- and nut-yielding trees and valuable timber trees that are gradually being concealed within the general forest matrix. A key example of the impact of tree planting is the patches of large *Liquidambar formosana*, which were planted by Tayal people to provide slope stability. Remnant *L. formosana* patches occur in numerous places along the transect, including in a former village site near V3, and on the hillslopes of V4, V5, and V6. In other areas there are patches of dense regrowth that occur following the selective harvest of *Cyclobalanopsis glauca*, *Quercus spinosa*, and about a half dozen other species as nurse logs for the cultivation of mushrooms. This was a form of agriculture that villagers relied on for several decades prior to 1990 (Icyeh 2011), and there are numerous areas throughout the study area where former mushroom cultivation gaps have filled in, appearing now as structural anomalies within the general forest cover.

CONCLUSIONS

Human land use has an enduring impact on forestland and it is therefore necessary to incorporate land use history when interpreting present forest characteristics. In this study, identification of past land uses helped to develop and explain a classification that distinguishes eleven forest types. The lower elevation forests demonstrate considerable patterning by human activity. Shifting cultivation, terrace farming, and settlement have resulted in anthropogenic forests that appear to expedite soil development as a result of long-term cultivation. These include red pine and bamboo forests, which are representative of terraced lands and former village sites, and alder forests, which occur on lands recently farmed with shifting cultivation. There is also a large extent of formerly cultivated lands in lower elevations that have had a longer fallow period following cultivation. These areas are represented by later successional oak and laurel forests that occur on poorly developed entisols, characteristics that may reflect a return to pre-disturbance conditions.

The findings in this study are resonant of the work of Ellen (2007) and others that show that forest-dwelling people play a key role in shaping forest. Though the Tayal Mrqwang people no longer engage in subsistence activities to the same extent as previous generations, legacies of past land use have endured and the landscape has retained a distinct and formative imprint of ancestral practices. The predominance of human use found in our study area provides strong evidence that other mountain regions in Taiwan are also shaped by past human uses. Published classifications for the region overlook the legacy of local people and do not acknowledge long-term and small-scale human interactions as factors that shape the landscape. Such classifications are bound to provide inappropriate reference targets to guide forest restoration and management on forestland that has a history of human activity. Furthermore, classifications that omit past land use impede cooperation between indigenous and non-indigenous stakeholders because they discount the history of local people and deepen the human–nature dichotomy. Scientific substantiation for the role of human agency in shaping forests may be one avenue toward facilitating dialog between indigenous people, scientists, and land managers in planning for resource management and establishment of protected areas.

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REFERENCES

Anderson, A.B., and D.A. Posey. 1989. Management of a tropical scrub savanna by the Gorotire Kayapó of Brazil. *Advances in Economic Botany* 7: 159–173.

Balée, W. 1994. *Footprints of the forest: Ka'apor ethnobotany—The historical ecology of plant utilization by an Amazonian people*. New York: Columbia University Press.

Barnes, B.V., K.S. Pregitzer, T.A. Spies, and V.H. Spooner. 1982. Ecological forest site classification. *Journal of Forestry* 80: 493–498.

Beers, T.W., P.E. Dress, and L.C. Wensel. 1966. Aspect transformation in site productivity research. *Journal of Forestry* 64: 691–692.

Berg, K. J. 2013. Ecological and Ethnoecological Classification of a Forested Landscape in the Tayal Mrqwang Territories, Taiwan (ROC). Ph.D. Thesis. Guelph, Canada: University of Guelph.

Bernard, H.R. 2002. *Research methods in anthropology: Qualitative and quantitative approaches*, 3rd ed. Walnut Creek, CA: AltaMira Press.

Bird, M.I., G. Hope, and D. Taylor. 2004. Populating PEP II: The dispersal of humans and agriculture through Austral-Asia and Oceania. *Quaternary International* 118–119: 145–163.

Bouchard, M., and D. Pothier. 2011. Long-term influence of fire and harvesting on boreal forest age structure and forest composition in eastern Quebec. *Forest Ecology and Management* 261: 811–820.

Bray, J.R., and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* 27: 325–349.

Chazdon, R.L. 2003. Tropical forest recovery: Legacies of human impact and natural disturbances. *Perspectives in Plant Ecology, Evolution and Systematics* 6: 51–71.

Chen, Y.-F. 2001. *Taiwan Vegetation (Volume 1): General Introduction to Vegetation Zones*. Taipei: Avanguard Publishing Company. **(in Chinese)**.

Chiou, C.-R., C.-F. Hsieh, J.-C. Wang, M.-Y. Chen, H.-Y. Liu, C.-L. Yeh, S.-Z. Yang, T.-Y. Chen, et al. 2009. The first national vegetation inventory in Taiwan. *Taiwan Journal of Forest Science* 24: 295–302.

Dambrine, E., J.-L. Dupouey, L. Laüt, L. Humbert, M. Thinon, T. Beaufils, and H. Richard. 2007. Present forest biodiversity patterns in France related to former Roman agriculture. *Ecology* 88: 1430–1439.

Dufrêne, M., and P. Legendre. 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs* 67: 345–366.

Edwards, C.R. 1986. The human impact on the forest in Quintana Roo, Mexico. *Journal of Forest History* 30: 120–127.

Ellen, R. 2007. Local and scientific understanding of forest diversity on Seram, Eastern Indonesia. In *Local science versus global science: Approaches to indigenous knowledge in international development*, ed. P. Sillitoe, 41–74. Oxford: Berghahn Books.

Fairhead, J., and M. Leach. 1995. False forest history, complicit social analysis: Rethinking some West African environmental narratives. *World Development* 23: 1023–1035.

Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, and A. Knapp. 2003. The importance of land-use legacies to ecology and conservation. *BioScience* 53: 77–88.

Foster, D.R., G. Motzkin, and B. Slater. 1998. Land-use history as long-term broad-scale disturbance: Regional forest dynamics in central New England. *Ecosystems* 1: 96–119.

Frazer, G.W., R.A. Fournier, J.A. Trofymow, and R.J. Hall. 2001. A comparison of digital and film fisheye photography for analysis of forest canopy structure and gap light transmission. *Agricultural and Forest Meteorology* 109: 249–263.

Gonsamo, A., and P. Pellikka. 2008. Methodology comparison for slope correction in canopy leaf area index estimation using hemispherical photography. *Forest Ecology and Management* 256: 749–759.

Higgs, E., D.A. Falk, A. Guerrini, M. Hall, J. Harris, R.J. Hobbs, S.T. Jackson, J.M. Rhemtulla, et al. 2014. The changing role of history in restoration ecology. *Frontiers in Ecology and the Environment* 12: 499–506.

Hsieh, C.-F., Z.-S. Chen, Y.-M. Hsu, K.-C. Yang, and T.-H. Hsieh. 1998. Altitudinal zonation of evergreen broad-leaved forest on Mount Lopei, Taiwan. *Journal of Vegetation Science* 9: 201–212.

Hsieh, C.-F., and C.-F. Shen. 1994. Introduction to the flora of Taiwan, 1: Geography, geology, climate, and soils. In *Flora of Taiwan, second edition: Volume One, Pteridophyta, Gymnospermae*, ed. C.-F. Hsieh, T.-C. Huang, H. Keng, W.-C. Shieh, J.-L. Tsai, J.-M. Hu, C.-F. Shen, and K.-C. Yang, 1–3. Taipei: National Taiwan University.

Hsieh, C.-F., C.-F. Shen, and K.-C. Yang. 1994. Introduction to the flora of Taiwan, 3: Floristics, phytogeography, and vegetation. In *Flora of Taiwan, second edition: Volume one, Pteridophyta, Gymnospermae*, ed. C.-F. Hsieh, T.-C. Huang, H. Keng, W.-C. Shieh, J.-L. Tsai, J.-M. Hu, C.-F. Shen, and K.-C. Yang, 7–18. Taipei: National Taiwan University.

Huang, T.-C., C.-F. Hsieh, H. Keng, W.-C. Shieh, J.-L. Tsai, J.-M. Hu, C.-F. Shen, and K.-C. Yang. 1994-2003. *Flora of Taiwan, Second Edition, Vols. 1–6*. Taipei: National Taiwan University.

Icyeh, L. 2011. *Tnunan Smangus: The mutual enjoyment, preservation and appreciation of Smangus*. Fushing Village: Shei-Pa National Park Headquarters.

Junqueira, A.B., G.H. Shepard Jr., and C.R. Clement. 2011. Secondary forests on anthropogenic soils of the middle Madeira River: Valuation, local knowledge, and landscape domestication in Brazilian Amazonia. *Economic Botany* 65: 85–99.

Kealhofer, L. 2003. Looking into the gap: Land use and the tropical forests of Southern Thailand. *Asian Perspectives* 42: 72–95.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: A numerical method. *Psychmetrika* 29: 115–129.

Levis, C., P.F. de Souza, J. Schietti, T. Emilio, J.L.P. da Veiga Pinto, C.R. Clement, and F.R.C. Costa. 2012. Historical human footprint on modern tree species composition in the Purus-Madeira Interfluve, Central Amazonia. *PLoS One* 7: 1–10.

Li, C.-F., M. Chytry, D. Zeleny, M.-Y. Chen, T.-Y. Chen, C.-R. Chiou, Y.-J. Hsia, H.-Y. Liu, et al. 2013. Classification of Taiwan forest vegetation. *Applied Vegetation Science* 16: 698–719.

Li, C.-F., D. Zeleny, M. Chytry, M.-Y. Chen, T.-Y. Chen, C.-R. Chiou, Y.-J. Hsia, H.-Y. Liu, et al. 2015. *Chamaecyparis* montane cloud forest in Taiwan: ecology and vegetation classification. *Ecological Research* 30: 771–791.

McCune, B., and J.B. Grace. 2002. *Analysis of ecological communities*. Gleneden Beach, OR: MjM Software Design.

Mielke Jr., P.W. 1984. Meteorological applications of permutation techniques based on distance functions. In *Handbook of statistics*, ed. P.R. Krishnaiah, and P.K. Sen, 813–830. Amsterdam: North-Holland.

Miller, A.M., and I.J. Davidson-Hunt. 2010. Fire, agency and scale in the creation of Aboriginal cultural landscapes. *Human Ecology* 38: 401–414.

Mueller-Dombois, D., and H. Ellenberg. 1974. *Aims and methods of vegetation ecology*. New York: Wiley.

Parker, A.J. 1982. The topographic relative moisture index: An approach to soil-moisture assessment in mountain terrain. *Physical Geography* 3: 160–168.

Peck, J.E. 2010. *Multivariate analysis for community ecologists: Step by step using PC-ORD*. Gleneden Beach, OR: MjM Software Design.

Peluso, N.L. 1996. Fruit trees and family trees in an anthropogenic forest: Ethics of access, property zones, and environmental change in Indonesia. *Comparative Studies in Society and History* 38: 510–548.

Pitty, A.F. 1978. *Geography and soil properties*. London: Methuen.

Sahu, P.K., R. Sagar, and J.S. Singh. 2008. Tropical forest structure and diversity in relation to altitude and disturbance in a Biosphere Reserve in central India. *Applied Vegetation Science* 11: 461–470.

Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, and W. D. Broderson. 2002. *Field book for describing and sampling soils, Version 2.0*. Lincoln, NE: Natural Resources Conservation Service, National Soil Survey Center.

Sheh, C.-S., and M.-K. Wang. 1991. *An atlas of major soils of Taiwan*. Taipei: Council of Agriculture, Executive Yuan.

Song, K., Q. Yu, K.K. Shang, T.H. Yang, and L.-J. Da. 2011. The spatio-temporal pattern of historical disturbances of an evergreen broadleaved forest in East China: A dendroecological analysis. *Plant Ecology* 212: 1313–1325.

Song, Y.-C., K.-S. Hsu, W.-L. Chen, X.-H. Wang, L.-J. Da, and T.-C. Chen. 2003. Evergreen broad-leaved forest in Taiwan and its relationship with counterparts in mainland China. *Acta Phytoecologica Sinica* 27: 719–732. **(in Chinese, English summary)**.

Song, Y.-C., and G.-S. Xu. 2003. A scheme of vegetation classification of Taiwan, China. *Acta Botanica Sinica* 45: 883–895.

Spies, T.A., and B.V. Barnes. 1985. A multifactor ecological classification of the northern hardwood and conifer ecosystems of Sylvania Recreation Area, Upper Peninsula, Michigan. *Canadian Journal of Forest Research* 15: 949–960.

Thomas, G.W. 1996. Soil pH and soil acidity. In *Methods of soil analysis, part 3. Chemical methods*, ed. J.M. Bartels, and J.M. Bigham, 475–490. Madison, WI: Soil Science Society of America and American Society of Agronomy.

Thompson, J., N. Brokaw, J.K. Zimmerman, R.B. Waide, E.M. Everham III, D.J. Lodge, C.M. Taylor, D. García-Montiel, et al. 2002. Land use history, environment, and tree composition in a tropical forest. *Ecological Applications* 12: 1344–1363.

United States Department of Agriculture (USDA). 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Second edition. Natural Resources Conservation Service, USDA-NRCS Agricultural Handbook, Number 436, Washington, DC.

van Gemerden, B.S., H. Olff, M.P.E. Parren, and F. Bongers. 2003. The pristine rain forest? Remnants of historical human impacts on current tree species composition and diversity. *Journal of Biogeography* 30: 1381–1390.

White, L.J.T., and J.F. Oates. 1999. New data on the history of the plateau forest of Okomu, southern Nigeria: An insight into how human disturbance has shaped the African rain forest. *Global Ecology and Biogeography* 8: 355–361.

Willis, K.J., L. Gillson, and T.M. Brncic. 2004. How ‘virgin’ is virgin rainforest? *Science* 304: 402–403.

Wysocki, D.A., P.J. Schoeneberger, and H.E. LaGarry. 2000. Geomorphology of soil landscapes. In *Handbook of Soil Science*, ed. M.E. Sumner, E5–E39. Boca Raton, FL: CRC Press LLC.

Yang, K.-C., J.-K. Lin, Y.-H. Wang, C.-F. Hsieh, and L.-H. Kuan. 2010. Vegetation composition and structure in the ecotone between deciduous and evergreen broad-leaved forests in an upstream region of Nantzuhsiensi, south-central Taiwan. *Taiwan Journal of Forest Science* 25: 41–52.

Yen, T.-M., Y.-J. Ji, and J.-S. Lee. 2010. Estimating biomass production and carbon storage for a fast-growing makino bamboo (*Phyllostachys makinoi*) plant based on the diameter distribution model. *Forest Ecology and Management* 260: 339–344.

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