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Research article

Patrones de estructura y diversidad de selva mediana subperennifolia bajo condiciones de gestión forestal

Patterns of structure and diversity in a medium sub-evergreen forest under forestry management conditions

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Resumen

Los patrones de la estructura de la vegetación (PEV) son afectados por la interacción dinámica entre los elementos sociales y ecológicos. El objetivo fue describir los patrones de la estructura y diversidad de la selva mediana subperennifolia después del aprovechamiento forestal maderable en Noh Bec, Quintana Roo, México. Se llevó a cabo un muestreo en las zonas de gestión forestal de manera simultánea en tres estadios de desarrollo del arbolado en unidades de muestreo rectangulares 10×50 m (fustales con *DN* [1.3 m]≥25 cm,), unidades jerárquicas cuadradas de 10 m (latizales con *DN*≥5 a<25 cm) y de 2 m (brinzales con *DN*<5 cm). Se calculó la estructura diamétrica, Índice de Valor de Importancia (*IVI*) y la diversidad alfa. Se registraron 70 especies (29 familias y 64 géneros), 52 675 individuos ha^{-1} en los brinzales, 1 015 individuos ha^{-1}, 9.51 m^2 ha^{-1} de área basal (*AB*) y 112.60 m^3 ha^{-1} de volumen total árbol (*VTA*) en latizales, y 95 individuos ha^{-1}, 12.08 m^2 ha^{-1} de *AB* y 145.41 m^3 ha^{-1} de *VTA* en fustales. La familia Sapotaceae reunió la mayor proporción de los *IVI*. *Pouteria reticulata* fue la especie más importante en los brinzales y latizales, en tanto que en los fustales fue *Manilkara zapota*. La diversidad de los PEV es evidente, sin embargo, es posible distinguirlos a través de indicadores específicos como el alfa de *Fisher* y los valores dasométricos estructurales.

Palabras clave: Brinzales, fustales, Gestión Forestal Comunitaria, latizales, Noh Bec, Plan Piloto Forestal.

Abstract

Vegetation structure patterns (VSP) are affected by the dynamic interaction between social and ecological elements. The objective was to describe the patterns of structure and diversity of the medium sub-evergreen forest after timber harvesting in *Noh Bec*, *Quintana Roo*, Mexico. The forest management areas were sampled simultaneously at three stages of tree development in 10×50-m rectangular sampling units (poles with *ND* [1.3 m]≥25 cm), and 10-m (saplings with *ND*≥5 to <25 cm) and 2-m square hierarchical units (seedlings with *DN*<5 cm). Diameter structure, Importance Value Index (*IVI*), and alpha diversity were calculated. Seventy species (29 families and 64 genera), 52 675 individuals ha^{-1} were recorded among the seedlings, 1 015 individuals ha^{-1}, 9.51 m^2 ha^{-1} of basal area (*BA*) and 112.60 m^3 ha^{-1} of total tree volume (*TTV*) among saplings, and 95 individuals ha^{-1}, 12.08 m^2 ha^{-1} of *BA* and 145.41 m^3 ha^{-1} of *TTV* among poles. The Sapotaceae family accounted for the largest proportion of the *IVI*. *Pouteria reticulata* was the most important species among the seedlings and saplings, while among the poles, it was *Manilkara zapota*. The diversity of the VSPs is evident, however, it is possible to distinguish them through specific indicators such as Fisher's alpha and structural dasometric values.

Keywords: Seedlings, poles, Community Forestry Management, saplings, *Noh Bec*, Pilot Forestry Plan.

Introduction

The jungles worldwide are located around the equator between 5 and 10° north and south (Corlett and Primack, 2011); the jungles in Mexico are located along the coasts of the Pacific Ocean and the Gulf of Mexico, in the states of *Chiapas* and *Tabasco*, extending to the Yucatan Peninsula (Miranda and Hernández-Xolocotzi, 2014). Rainforests are one of the most important carbon reservoirs in the world and are home to a large proportion of the tree species found in all ecosystems on the planet (Bonnell *et al.*, 2011). For years, they have been affected by natural and anthropogenic disturbances (Navarro-Martínez *et al.*, 2012), particularly in the Yucatan Peninsula, where vegetation has exhibited changes in species composition and dominance after the impact of hurricanes such as Dean and *Gilberto*, with small reductions of species richness (Sánchez and Islebe, 1999; Navarro-Martínez *et al.*, 2012).

The effects of selective logging have been discussed by several authors (Kammesheidt, 1998; Edwards *et al.*, 2014; Ding *et al.*, 2017) in terms of timber production (Hall *et al.*, 2003; Brown and Gurevitch, 2004; Villela *et al.*, 2006) and biodiversity conservation (Burivalova *et al.*, 2014; Edwards *et al.*, 2014).

Tree structure patterns are mainly affected by the dynamic interaction between social and ecological elements, as a consequence of the nature of the socioeconomic systems that regulate these (Gardner *et al.*, 2009).

Forest management has a variable effect on tree diversity (Monárrez-González *et al.*, 2018), can modify the structure and composition of the forest favoring certain species, and evinces a synergistic or compensatory relationship between forest management and biodiversity (Monárrez-González *et al.*, 2018). In addition, hurricanes also create adverse or favorable conditions, as they modify the richness of tree species (Gutiérrez-Granados *et al.*, 2011; Pat-Aké *et al.*, 2018), which establishes different patterns of tree structure in reduced areas of the same vegetation type, according to the capacity to recover the equilibrium after the effect of the disturbance (Pimm, 1984).

This paper analyzes the patterns of structure and diversity in a medium sub-evergreen forest after timber harvesting under three forest management conditions: seedlings, saplings, and poles under the assumption that species richness and diversity, as well as structural importance values, are statistically equal among the three forest management conditions.

Materials and Methods

Study area

The *Noh Bec ejido* is located in the municipality of *Felipe Carrillo Puerto*, *Quintana Roo*, with a surface area of 24 122.88 ha (Phina, 2018), between coordinates 19°02'30" and 19°12'30" N and 88°13'30" and 88°27'30" W (Pat-Aké *et al.*, 2018) (Figure 1). The *Noh Bec ejido* has a permanent forest area (PFA) of 18 510 ha (87 % of the total area) that is used for timber and non-timber forest harvesting. The study area covered 10 580 ha of the PFA of medium sub-evergreen forest (Pennington and Sarukhán, 2005). The climate is warm sub-humid (Aw_1 (x')), with rainfall in summer and part of the winter, the average annual rainfall is 1 200 mm, and the average temperature varies between 18 and 26 °C (García, 2004).

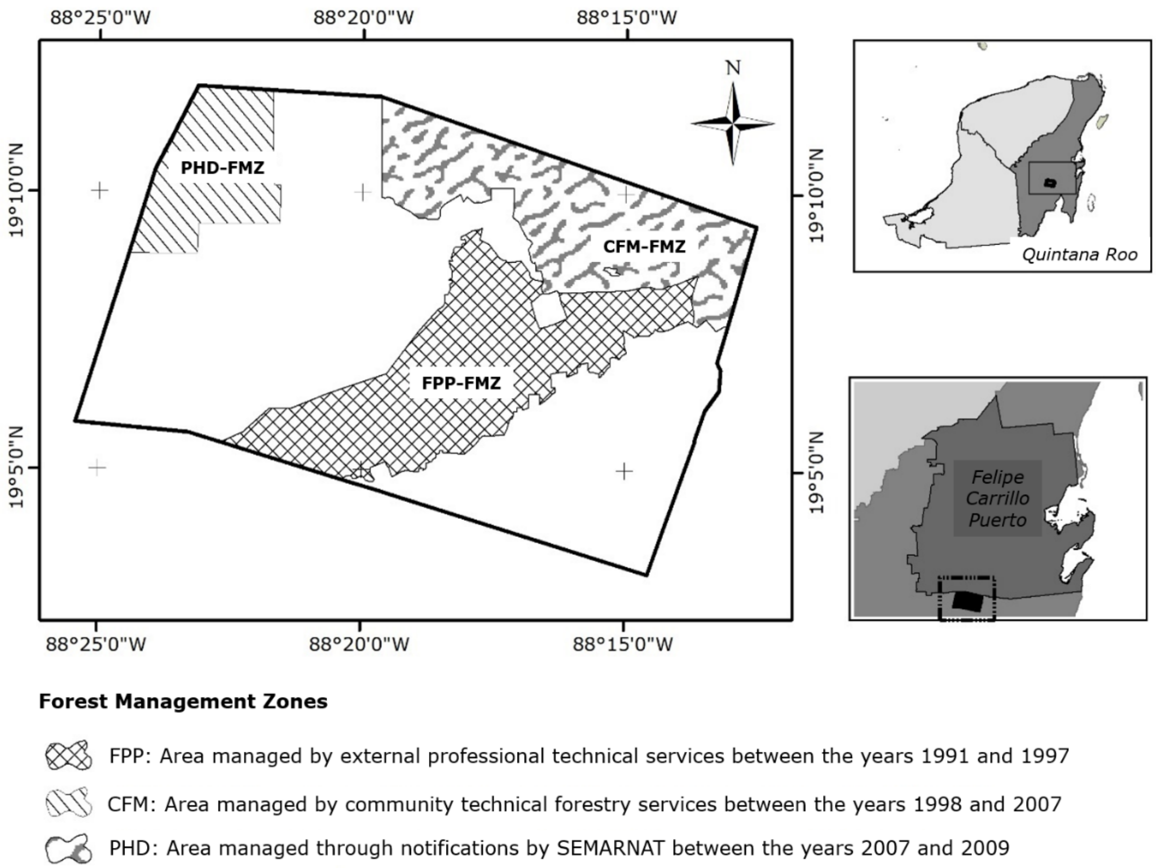


Figure 1. Location of forest management zones in the permanent forest area of the *Noh Bec ejido*, *Quintana Roo*, Mexico.

Field sampling

The tree vegetation was divided into three stages of development for sampling purposes: seedlings, saplings, and poles according to Alvis (2009). Field data were collected in 2015 with 300 randomly distributed sampling units (SUs) in 10×50 m rectangular Sampling Units (SU). Mature trees (poles) with a normal diameter (*ND*) (measured at 1.3 m from the ground) of 25 cm or more were registered. 300 square units of 10 m were counted for medium-sized trees (saplings) with a diameter of 5 cm to less than 25 cm, and 300 square units of 2 m for young trees (saplings) with a diameter of less than 5 cm. The *ND* of all individuals with 5 cm or more was measured with a model 283/5m Forestry Suppliers® diameter tape. For individuals with a *ND* of less than 5 cm, the count was made by species.

The sampling was distributed in three areas belonging to three forest management programs (FMPs): management zone corresponding to the time of the forestry pilot plan (FPP-MZ), forest management zone corresponding to the time of the beginning of community forest management (CFM-MZ), and post-hurricane Dean management zone (PHD-MZ), this zone was managed according to criteria of rescue of felled and plagued trees of commercial interest authorized through notifications and a simplified level authorization document.

Horizontal structure

Diameter categories were determined with inflection points of a curve of the number of individuals and diameter (López-Toledo *et al.*, 2012) in order to establish the number of possible groupings. The appropriate clustering of diameter categories (*k*) ($P \leq 0.0001$) was estimated with the partitioning around medioids method (PAM) (Rousseeuw, 1987; Tadeo-Noble *et al.*, 2019).

Structural importance

The Importance Value Index (*IVI*) of the saplings and poles species was estimated according to Beltrán-Rodríguez *et al.* (2018), expressed as a percentage.

$$IVI = \frac{RF + RD + RDo}{3} \quad (1)$$

Where:

RF = Relative frequency

RD = Relative density

RDo = Relative dominance

In the case of the saplings, the modified *IVI* was calculated for each species because diameters were not measured in this sampling (Tadeo-Noble *et al.*, 2019).

$$IVI_M = \frac{RF + RD}{2} \qquad (2)$$

Where:

RF = Relative frequency

RD = Relative density

Alpha diversity

The alpha diversity of the species was estimated with the Margalef Index (Magurran and McGill, 2011):

$$D_\alpha = \frac{(S-1)}{(Log_e(N))} \qquad (3)$$

Where:

S = Number of species

N = Total number of individuals

Simpson's Index (Magurran, 1988) defined as:

$$\lambda = \frac{1}{\Sigma\left(\frac{n_i(n_i-1)}{N(N-1)}\right)} \qquad (4)$$

Where:

n_i = Number of individuals of species *i*

N = Total number of individuals

The following formula was used to calculate the Fisher Alpha Index (*FAI*) (Magurran, 2013):

$$S = \alpha \ ln\left(1 + \frac{N}{\alpha}\right) \quad (5)$$

Where:

S = Number of species

α = Fisher's Alpha Diversity Index

N = Total number of individuals

Fisher's *α* values are expressed with 95 % confidence intervals (Hayek and Buzas, 2010; Magurran, 2013).

$$CI = \alpha \pm 1.96 \times SE \quad (6)$$

Where:

α = Punctual value of Fisher’s alpha diversity index

SE = Standard error

Species heterogeneity

Heterogeneity (Magurran, 1988) expressed as:

$$H' = -\sum(p_i \times ln(p_i)) \quad (7)$$

Where:

pi = Proportion of individuals in the total sample corresponding to the i^{th} species

Hutcheson's (1970) method was used to test for differences in heterogeneity between two study areas (Beltrán-Rodríguez *et al.*, 2018).

Species equity

The ratio of the observed diversity to the maximum diversity is a measure of species' partitioning (Magurran, 1988; Carreón-Santos and Valdez-Hernández, 2014) estimated as:

$$E = \frac{H'}{ln(S)} \quad (8)$$

Where:

H' = Shannon-Wiener index

S = Number of species

Statistical analysis

The Importance Value Index (*IVI*) was evaluated by performing a Wilcoxon rank test (Muñoz *et al.*, 2017) and Spearman's correlation (Zar, 2010) was estimated. The estimation of richness indices, alpha diversity indices, heterogeneity and Fisher's alpha was performed in the Species Diversity & Richness (SDR) software version 4.1.2 (Seaby and Henderson, 2006), and for statistical comparisons of the number of species, Margalef, Equity and Simpson's inverse; we used Solow's (1993) sample randomization test proposal included in the SDR software.

Results and Discussion

Structural attributes

The values of density of individuals, basal area, and total tree volume in the three forest management zones (Table 1) are very similar to the patterns quoted by Tadeo *et al.* (2014), Pat-Aké *et al.* (2018), and Tadeo-Noble *et al.* (2019) for the same study area and similar to those pointed out by Negreros-Castillo *et al.* (2014) in medium sub-evergreen forest with timber forest management.

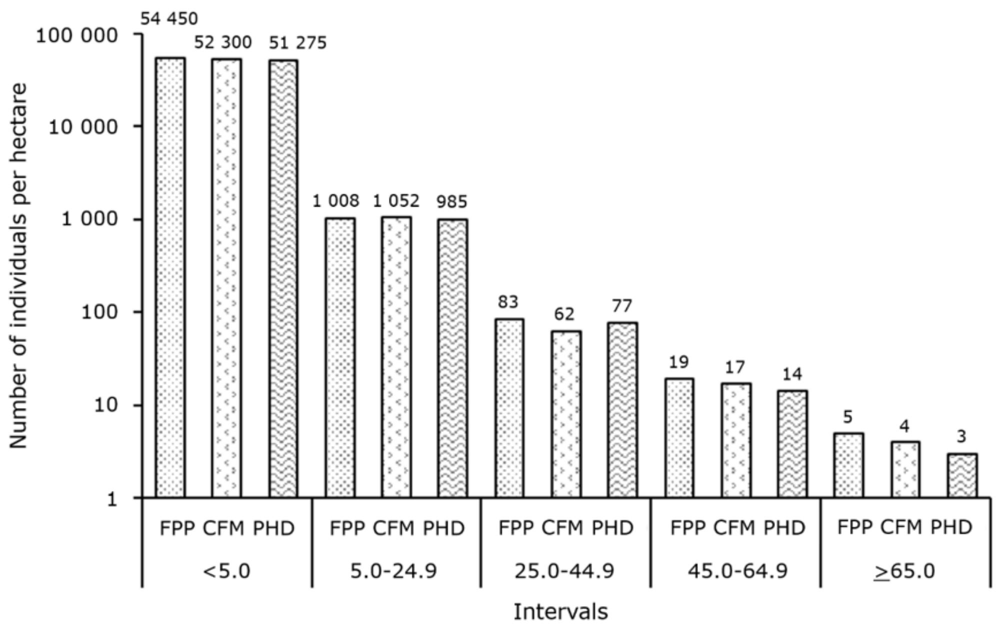
Table 1. Structural values of the forest management zones of the *Noh Bec ejido*, Quintana Roo, Mexico.

Stage of development	**Forest management zone**	**Density of individuals (ind. ha^{-1})**	**Basal area (m^2 ha^{-1})**	**Total tree volumen (m^3 ha^{-1})**	**Sample (*n*)**
Seedlings	FPP	54 450±3 794 a			100
	CFM	52 300±3 224 a			100
	PHD	51 275±4 034 a			100
	Av.±SE	52 675±2 130			
Saplings	FPP	1 008±47 a	8.95±0.47 a	104.61±5.49 b	100
	CFM	1 052±47 a	9.48±0.58 a	109.40±6.72 ab	100
	PHD	985±57 a	10.06±0.71 a	123.62±8.88 a	100
	Av.±SE	1 015±29	9.51±0.34	112.60±4.16	
Poles	FPP	107±5 a	14.15±0.80 b	171.43±9.88 b	100
	CFM	83±4 c	10.93±0.71 a	131.91±9.28a	100
	PHD	94±5 b	11.18±0.64 a	132.88±8.20 a	100
	Av.±SE	95±3	12.08±0.42	145.41±5.37	

FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean; *Av.±SE* = Average±standard error. Values of a parameter followed by different letters between management zones indicate a significant difference ($p<0.05$).

Diameter distribution

The diameter distribution of the three management zones tends to the left in the form of an inverted jack, the values in the normal diameter (*ND*) went from 5 cm to 130, 107, and 110.1 cm, depending on the management zone (FPP, CFM, and PHD) (Figure 2). The highest density was concentrated in the first diameter interval (Zamora *et al.*, 2008; Tadeo-Noble *et al.*, 2019), the proportions of diameter intervals below 25 cm coincide with the data published by García-Licona *et al.* (2014). The diameter distribution showed a substantial and progressive decrease as it moved away from the smaller diameters, a pattern that is described for the medium sub-deciduous forest (Gutiérrez *et al.*, 2011).



FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean.

Figure 2. Diametric stratification of trees in the management zones based on the partitioning method and allocation of data generated from medioids.

Importance value of vegetation in the different management zones

The first three places of IVI_M in seedlings, saplings, and poles did not correspond to the same species, there were only changes of place between them. In the case of the seedlings, four of the IVI_M species are canopy-dominant trees, two examples are *Brosimum alicastrum* Sw. (Moraceae) and *Manilkara zapota* (L.) P. Royen (Sapotaceae). The most important saplings species within the *Noh Bec* forest structure are *Pouteria reticulata* (Engl.) Eyma and *Damburneya patens* (Sw.) Trofimov (Table 2), which grow under the canopy. The jungle of *Quintana Roo* is a place characterized by endemisms, *e. g.*, the presence, in the medium sub-evergreen forest, of *Cryosophila stauracantha* (Heynh) R. Evans, an abundant species in this stratum (Ibarra-Manriquez *et al.*, 1995; Martínez and Galindo-Leal, 2002; Pennington and Sarukhán, 2005).

Table 2. Modified Importance Value Indices (IVI_M) of the best represented sapling species by management zones.

Scientific name	Family	FPP	CFM	PHD	*WA*
Pouteria reticulata (Engl.) Eyma	Sapotaceae	21.27	30.37	27.67	26.43
Cryosophila stauracantha (Heynh.) R. Evans	Arecaceae	13.08	10.83	7.97	10.63
Damburneya patens (Sw.) Trofimov	Lauraceae	8.17	8.53	13.00	9.90
Piper aduncum L.	Piperaceae	9.39	7.32	8.57	8.43
Psidium oligospermum DC.	Myrtaceae	5.91	7.76	8.25	7.31

Trichilia minutiflora Standl.	Meliaceae	5.16	3.58	3.37	4.04
Brosimum alicastrum Sw.	Moraceae	3.19	4.82	3.14	3.72
Manilkara zapota (L.) P. Royen	Sapotaceae	1.78	2.68	3.17	2.55
Pithecellobium dulce (Roxb.) Benth.	Fabaceae	2.52	1.33	2.23	2.03
Karwinskia humboldtiana (Schult.) Zucc.	Rhamnaceae	4.30	0.44	0.20	1.65
Protium copal (Schltdl. & Cham.) Engl.	Burseraceae	1.15	1.65	1.32	1.37
Sabal yapa C. Wright *ex* Becc.	Arecaceae	1.85	0.85	1.39	1.36
Mosannona depressa (Baill.) Chatrou	Annonaceae	1.09	1.19	1.41	1.23
Metopium brownei (Jacq.) Urb.	Anacardiaceae	0.62	1.24	1.72	1.19
Gymnanthes lucida Sw.	Euphorbiaceae	0.42	1.92	1.19	1.17
Cupania belizensis Standl.	Sapindaceae	2.14	0.85	0.41	1.13
Lucuma campechiana Kunth	Sapotaceae	1.04	1.38	0.81	1.08
Pimenta dioica (L.) Merr.	Myrtaceae	1.02	1.01	0.89	0.97
Subtotal (18)		84.1	87.7	86.7	86.2
Other species (39, 38, 34)		15.9	12.2	13.2	13.8
Total		100	100	100	100

FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean; *WA* = Weighted average.

The three taxa with the greatest structural importance among the saplings were: *Pouteria reticulata*, *Alseis yucatanensis* Standl. (Rubiaceae), and *Drypetes lateriflora* (Sw.) Krug & Urb. (Putranjivaceae). Half of the outstanding species are commercially important timber trees regulated by the logging program and they can dominate the canopy, two examples are *Dendropanax arboreus* (L.) Decne. & Planch. (Araliaceae) and *Metopium brownei* (Jacq.) Urb. (Anacardiaceae) (Table 3).

Table 3. Importance index values for the best-represented species by management zone for saplings.

Scientific name	Family	FPP	CFM	PHD	WA
Pouteria reticulata (Engl.) Eyma	Sapotaceae	27.39	24.27	23.60	25.09

Alseis yucatanensis Standl.	Rubiaceae	7.28	9.08	6.68	7.68
Drypetes lateriflora (Sw.) Krug & Urb.	Putranjivaceae	3.30	4.13	4.44	3.96
Sabal mauritiiformis (H. Karst.) Griseb. & H. Wendl.	Arecaceae	5.43	2.38	3.77	3.86
Brosimum alicastrum Sw.	Moraceae	3.56	3.43	1.94	2.98
Blomia prisca (Standl.) Lundell	Sapindaceae	1.70	3.07	4.05	2.94
Damburneya patens (Sw.) Trofimov	Lauraceae	3.23	4.63	0.93	2.93
Lucuma campechiana Kunth	Sapotaceae	2.93	3.13	2.41	2.82
Bursera simaruba (L.) Sarg.	Burseraceae	1.51	2.61	3.99	2.70
Manilkara zapota (L.) P. Royen	Sapotaceae	3.41	2.68	1.18	2.42
Dendropanax arboreus (L.) Decne. & Planch.	Araliaceae	2.30	2.33	2.47	2.37
Sabal yapa C. Wright ex Becc.	Arecaceae	1.46	3.53	1.86	2.28
Trichilia minutiflora Standl.	Meliaceae	2.72	1.67	2.28	2.22
Protium copal (Schltdl. & Cham.) Engl.	Burseraceae	2.00	1.63	2.68	2.10
Gymnanthes lucida Sw.	Euphorbiaceae	1.00	3.26	1.63	1.96
Pithecellobium dulce (Roxb.) Benth.	Fabaceae	3.52	1.15	0.69	1.79
Mosannona depressa (Baill.) Chatrou	Annonaceae	1.43	1.87	1.49	1.60
Guettarda combsii Urb.	Rubiaceae	1.30	0.96	2.37	1.54
Subtotal (18)		75.47	75.81	68.46	73.25
Other species (50, 44, 52)		24.53	24.19	31.54	26.75
Total		100	100	100	100

FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean; *WA* = Weighted average.

Importance Value Index in poles. The three species with the greatest structural importance were: *Manilkara zapota* (Sapotaceae), *Brosimum alicastrum* (Moraceae), and *Lucuma campechiana* Kunth (Sapotaceae). A family or a single species may account for more than 30 % of the value of a structural parameter (Okuda *et al.*, 2003; Dzib-Castillo *et al.*, 2014), as was the case in this study of the Sapotaceae family for the *IVI* (Toledo-Aceves *et al.*, 2009; Tadeo-Noble *et al.*, 2019) (Table 4).

Table 4. Importance index values for the best-represented species by management zone for the poles.

Scientific name	Family	FPP	CFM	PHD	WA
Manilkara zapota (L.) P. Royen	Sapotaceae	23.59	22.75	19.13	21.82
Brosimum alicastrum Sw.	Moraceae	16.87	14.61	15.79	15.75
Lucuma campechiana Kunth	Sapotaceae	5.47	7.20	5.69	6.12
Vitex gaumeri Greenm.	Lamiaceae	6.39	5.53	6.14	6.02
Pseudobombax ellipticum (Kunth) Dugand	Malvaceae	3.59	8.08	6.12	5.93
Simira salvadorensis (Standl.) Steyerm.	Rubiaceae	7.41	3.41	4.51	5.11
Metopium brownei (Jacq.) Urb.	Anacardiaceae	3.61	3.31	3.77	3.56
Bursera simaruba (L.) Sarg.	Burseraceae	3.80	2.08	3.34	3.07
Lysiloma latisiliquum (L.) Benth.	Fabaceae	0.75	1.82	6.27	2.95
Simarouba glauca DC.	Simaroubaceae	2.17	3.14	2.91	2.74
Luehea speciosa Willd.	Malvaceae	2.86	1.60	2.54	2.34
Pouteria reticulata (Engl.) Eyma	Sapotaceae	1.77	3.04	1.59	2.13
Swartzia cubensis (Britton & P. Wilson) Standl.	Fabaceae	2.14	2.57	1.66	2.13
Dendropanax arboreus (L.) Decne. & Planch.	Araliaceae	1.82	1.31	3.13	2.09
Guettarda combsii Urb.	Rubiaceae	1.37	2.41	1.98	1.92
Swietenia macrophylla King	Meliaceae	1.69	2.95	0.93	1.86
Blomia prisca (Standl.) Lundell	Sapindaceae	1.47	2.12	1.63	1.74
Piscidia piscipula (L.) Sarg.	Fabaceae	1.75	0.89	2.56	1.73
Subtotal (18)		88.52	88.81	89.71	89.01
Other species (38, 37, 34)		11.48	11.19	10.29	10.99
Total		100	100	100	100

FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean; *WA* = Weighted average.

Richness and composition

The species richness and composition differed in each stage and management zone. The floristic composition was basically dominated by three families in the different samplings: Fabaceae (11, 16, 12), Rubiaceae (7, 6, 5), and Sapindaceae (6), which registered the highest number of genera and species; these data agree with those reported by García-Licona *et al.* (2014) and Granados-Victorino *et al.* (2017) in a medium sub-evergreen forest in *Campeche* and *Hidalgo*, respectively.

The recovery of the zones can be described as a unique and differentiated pattern over time (Carreón-Santos and Valdez-Hernández, 2014). The predominance of certain families is very similar to that observed in some medium-sized unmanaged forests (Navarro-Martínez *et al.*, 2012; Carreón-Santos and Valdez-Hernández, 2014), unlike in other tropical scenarios in Mexico (Gutiérrez-Granados *et al.*, 2011).

Diversity of species

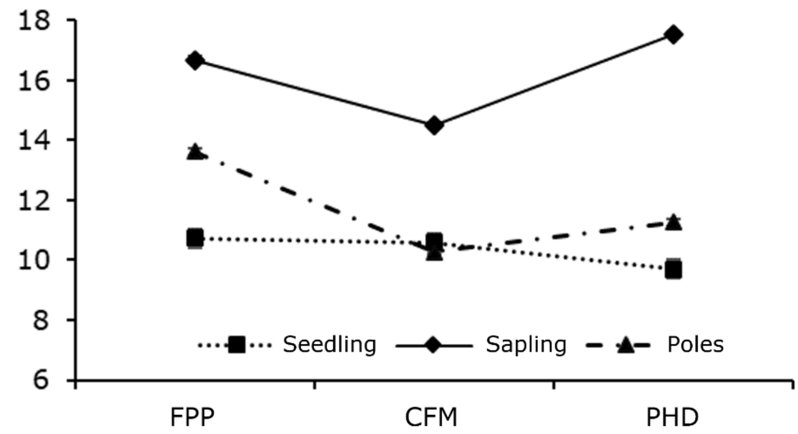
Values between management zones and developmental stages are heterogeneous, for example, equity indices differed only among seedlings, but the richness was similar within management zones. Heterogeneity and equity at *Noh Bec* (*H'*=2.19-3.15; *U*=0.54-0.79) (Table 5) is considered to be similar to other jungles in *Quintana Roo* (*H'*=2.78-3.33; *U*=0.76-0.83) (Carreón-Santos and Valdez-Hernández, 2014) and below the values recorded for logged forests in *Quintana Roo* (*H'*=2.52-2.85; *U*=0.83-0.96) (Navarro-Martínez *et al.*, 2012).

Table 5. Species richness and diversity values by forest management zone and stage of development of tree species.

Stage of development	Forest management zone	Species richness (individuals)	Genera (Families)	Equity	Inverse Simpson	Margalef	Shannon
Seedlings	FPP	57 (2 178) a	50 (24)	0.65 a	7.83 a	7.29 a	2.64 a
	CFM	56 (2 092) a	54 (26)	0.54 b	4.22 b	7.19 a	2.19 b
	PHD	52 (2 051) a	49 (26)	0.57 b	4.84 b	6.69 b	2.26 b
Saplings	FPP	68 (968) a	61 (29)	0.69 a	6.90 a	9.74 a	2.91 a
	CFM	62 (1 031) b	56 (25)	0.73 a	8.34 a	8.79 b	3.02 a
	PHD	70 (966) a	64 (27)	0.74 a	7.88 b	10.04 a	3.15 a
Poles	FPP	50 (520) a	47 (22)	0.73 a	9.84 b	7.84 b	2.87 b
	CFM	38 (404) b	35 (17)	0.79 a	11.55 a	6.17 a	2.87 a
	PHD	42 (457) a	38 (20)	0.78 a	13.73 a	6.69 a	2.91 a

FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean. The values of a parameter followed by different letters between management areas differ significantly ($p<0.05$).

Fisher's Alpha Index (*FAI*) values exhibited no significant differences at the developmental stage level. The highest *FAI* values were registered in the saplings. The general disposition of the *FAI* point values was very similar between saplings and poles, unlike in the seedlings, the trend was reversed (Figure 3).



FPP = Forestry pilot plan; CFM = Community forestry management; PHD = Post-hurricane Dean.

Figure 3. Fisher's Alpha Index values with 95 % confidence intervals by stage of development and management area.

These findings support the viability of sustainable forest management in these forests, and demonstrate that timber harvesting does not significantly affect species richness, as pointed out by Vester and Navarro-Martínez (2005). However, some influence on structural parameters and species composition is observed, but the impacts are minimal. Parallel research in Central African rainforests by Hall *et al.* (2003) and in Brazilian forests by Villela *et al.* (2006), who also concluded that forest harvesting through selective techniques does not compromise the biological diversity.

Conclusions

The various harvesting intensities applied in each forest management zone and at each serial stage reveal that these ecosystems can be compared, in terms of richness and diversity, with others located in *Quintana Roo*, *Campeche* and *Veracruz*. The tree structure patterns are heterogeneous, but distinguishable in some indices, particularly in Fisher's Alpha and structural dasometric values, unlike the diameter distribution which, although similar in trend within the categories, shows variations that are related to the forest harvesting regimes.

Structure, composition, and diversity studies are essential for timber forest management, as they provide key arguments and establish detailed protocols, along with a solid baseline for effective monitoring and evaluation of future timber harvesting activities.

The *Noh Bec ejido*, in the medium sub-evergreen forest of *Quintana Roo*, is a model of sustainable forest management that demonstrates how conservation and timber production can coexist, benefiting the environment and the community, preserving the ecosystem and contributing to sustainable development in Mexico.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Alfredo Esteban Tadeo-Noble: conceptualization and study design, statistical analysis and writing of the final manuscript; Edmundo García Moya: training, capabilities development and review of the manuscript; Juan Ignacio Valdez Hernández: conceptualization and study co-design; Lauro López Mata: review and monitoring of results; Mario Luna Cavazos: formation, analysis and interpretation of results; Héctor Manuel De Los Santos Posadas: statistical counseling, interpretation of results and review of the final manuscript; José Luis Hernández Stefanoni: counseling in the sample design, interpretation of results and review of the final manuscript.

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