Journal of Environmental Analysis and Progress

ISSN: 2525-815X

Journal homepage:
10.24221/jeap.8.1.2023.4672.030-037

Application of soil seed bank techniques to facilitate forest restoration in the Caatinga

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A R T I C L E I N F O

Recebido 07 Oct 2021
Aceito 10 Jan 2023
Publicado 27 Mar 2023

A B S T R A C T

Nucleation is a technique widely used in restoration projects, but the transposition of the seed bank in the soil with greater depth is still incipient, especially in the Caatinga Biome. Thus, it evaluated whether the two seed bank transposition techniques (litter and topsoil) collected in two natural environments of the Mata da Pimenteira State Park (PEMP) provide seedling emergence in degraded areas of the Caatinga. Litter and topsoil techniques were transported from two Natural Environment Zone (ZAN) of the park, Serra Branca and Pimenteira, to two restoration areas in UFRPE/UAST in plots distributed in nuclei. The design was in randomized blocks, for litter in 2016 and topsoil in 2017. The highest average of emerging seedlings occurred in the surface forest soil transposition (topsoil) technique, mainly in the collection environment of the pepper tree area of the Pimenteira State Park. Herbaceous (herbs) were more evident in the topsoil (63.25%) than in litter (61%) and the species *Alcalypha poiretii* Spreng. was the most abundant in the Pimenteira area while the species *Croton hirtus* L'Hér. in the Serra Branca. The topsoil technique showed higher species richness, while litter was less uniform. However, both techniques presented a potential for species conservation, and the Pimenteira environment provided higher viable seed bank potential in degraded areas under Caatinga ecosystem conditions.

Keywords: Nucleation, topsoil, litter, degraded areas.

Introduction

The forest restoration methods are applied to facilitate the natural process of ecological succession, both on sites that have some natural regeneration and on sites without any potential for natural regeneration (low quantity of seed and young individuals) and with low recovery rates in an adequate amount of time (Brancalion et al., 2015).

On sites with regenerating individuals of native species, nucleation techniques facilitate the future recovery of the area at a reduced cost. Among these techniques, the induction of the seed bank (plant litter and topsoil) is suggested as a direct transfer of propagules contained in forest soil, insect spreaders, earthworms, microorganisms, and seeds.

The soil transfer technique in deeper layers is performed in several Brazilian biomes; however, in the Caatinga biome, only the plant litter is used, with superficial soil material (5 cm) (Santos et al., 2016) or suspended collectors (Brasil et al., 2017; Silva et al., 2016; Holanda et al., 2017), in which leaves, branches, reproductive material (fruits, flowers, and seeds), and miscellaneous (animal excreta) are present. Costa & Arajo (2003) discovered a greater number of emerging seedlings in the superficial layers of plant litter and at depths of 0-5 cm compared to 5-10 cm. This way, the most superficial layer of the soil became more evident to demonstrate the number of emerging seedlings in the Caatinga biome; however, in deeper layers (topsoil), more seeds are found, although the soils of the semiarid region are shallow, and have an impervious layer (Gama & Jesus, 2020).

Conversely, seed bank collection sites influence seed quantity and quality and can contribute to increasing species richness and abundance on degraded sites.

In the Conservation Unit of Mata da Pimenteira State Park, two areas of the natural environment can provide a potential seed bank to be transplanted in degraded areas. The Serra Branca area has trees with a medium canopy, higher light incidence, and rockier soil on a slope in an area of medium regeneration, while Pimenteira presents a more preserved area characteristic of a mature forest, with intermittent streams (Melo et al., 2013).

In this regard, the goal of this study is to evaluate if the two techniques of seed bank transposition (plant litter and topsoil) collected in two natural environments of the Mata da Pimenteira State Park (Pimenteira and Serra Branca) provide seedling emergence in degraded areas of the Caatinga, besides exploring the diversity of emerging species.

Materials and Methods

Study area

The research was conducted in the city of Serra Talhada in the state of Pernambuco, a Caatinga region with a Köppen climate classification of BSwh (Pernambuco, 2013), with the rainy season, limited to the months between November and April, with an average precipitation of 642,1 mm and an average temperature of 24.8 °C (Silva et al., 2015).

To explore the seed bank, plant litter, and topsoil were collected in two Natural Environment Zones (ZAN) of the Mata da Pimenta State Park (PEMP), with an average distance of 6 km. The first collection area, Serra Branca (ZAN 1), has predominantly rocky outcrops with shrubby-herbaceous vegetation and is situated at an average altitude of 650 m. The second one, Pimenteira (ZAN 2), has a more uniform composition, with flat topography and an altitude of 500 m, where its vegetation is more structured between the tree and shrub-tree species, surrounded by temporary streams (Melo et al., 2013) (Figure 1).

The material was inserted in a degraded area, aimed for regeneration, located in the Federal Rural University of Pernambuco, Academic Unit of Serra Talhada (UFRPE/UAST) (Figure 1), with an extension of 2,500 m², among tree remnants about 2 km from ZAN 1 and 8 km from ZAN 2. The area was managed for three years with green manure (*Crotalaria juncea* L.) for its coverage, and subsequently, native tree species were inserted.

Figure 1. Natural Environment Zone (ZAN) from which materials were collected within the Mapa da Pimenteira State Park (PEMP), and the location of the degraded area of deposition at the Federal Rural University of Pernambuco-UFRPE/Academic Unit of Serra Talhada-UAST. Font: Google Earth. Accessed on: January 27, 2018.

The seed bank was evaluated in the field for two years (2016 and 2017). In the first year, 10 samples of 0.05 m³ of plant litter were collected in each ZAN at places 10 m apart to ensure greater representativeness of the area, and in the second year, the samples collected were composed of topsoil of 0.1 m^3.

The experimental design used was a randomized block design, in which materials collected from the two park areas (ZAN1 and ZAN2) using two distinct techniques (plant litter and topsoil) were transposed to plots of 1m² located in two blocks with 20 experimental units (10 in each year).

Plant litter technique

The material was inserted in the center of each plot, making up a 50 cm x 50 cm area (Figure 2A), with a distance of 20 cm from the edges to avoid the influence of surrounding individuals. In addition, control plots were inserted without the transposition of material to distinguish species emerging from the local seed bank and the transcribed material (Figure 2B)

Figure 2. A. Plot in the field with material; B. Local control plot. Font: Saraiva et al. (2018).

Topsoil

The material was transposed to the center of the plot and inserted during the rainy season (February) to keep the material moist and more adhered to the soil, avoiding losses caused by wind since the study was conducted in dryland, depending exclusively on local precipitation.

Evaluation

The evaluation of the seed bank was done by surveying the emerging seedlings, counting them, and identifying them within the plots. Throughout these evaluations, the grass species were removed to reduce competition among emerging plants. The identification was done from representative samples of each individual (leaf, flower, and fruit), which were sent to the Herbarium of Semiarid Brazil (HESBRA) of UFRPE/UAST to proceed with the taxonomic identification of species with the help of available material (bibliography and exsiccate).

Taxonomic identification was done at the family, genus, and species levels, as well as growth habit recording. After that, the data were evaluated by describing the species observed, determining richness, and making Whittaker's diagrams to determine abundance, with exploration between the collection areas (ZAN 1 and ZAN 2) and material used (plant litter and topsoil).

Results and Discussion

The topsoil transposition technique showed a higher average number of emerging seedlings compared to the plant litter technique, especially in the collection environment of the Pimenteira area of Pimenteira State Park (Figures 3A and 3B). This was due to the forest topsoil being composed of a deeper layer of the soil surface, about 10 cm or more, while the plant litter was composed of only 5 cm, with a greater predominance of leaves, branches, and some seeds. Therefore, the topsoil carried a higher density of seeds and with greater variability, a fact similar to the study by Rodrigues et al. (2010), who obtained higher seed density in areas with treatments of soil seed bank plus plant litter and soil seed bank and decreased in plant litter and the control sample in a semideciduous seasonal forest in the Southeast of Brazil. Such a comparison points out that, even in different ecosystems (Atlantic Forest and Caatinga), the seed bank at greater depths has a higher seed density.

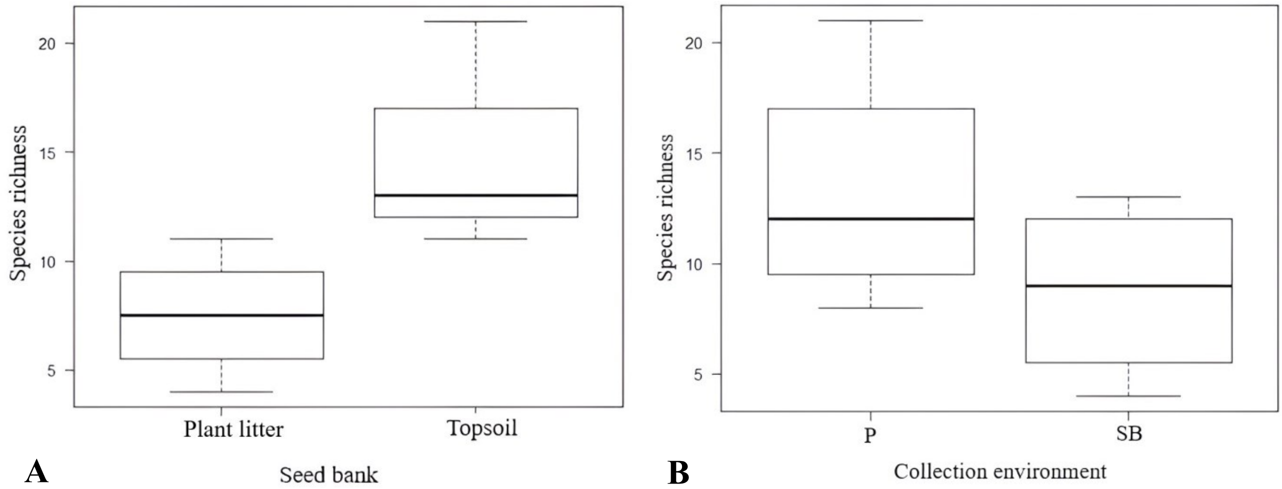

Figure 3. Species richness among seed banks (plant litter and topsoil) (A) and collection sites in the studied environments (Pimenteira and Serra Branca) (B) in 2018. Font: Saraiva et al. (2021).

Considering the conditions of the study region, the depth of soil collection is very important for forest restoration projects because the seeds located on the surface are more susceptible to weather conditions, such as dry periods with low availability of rainfall and high luminosity and temperature, which favor the mechanism of dormancy and consequently a lower number of emerging seedlings. Thus, the superficial forest soil in the Pimenteira environment showed higher average species richness than in the Serra Branca environment of PEMP (Figure 3B), in degraded areas without irrigation. The Pimenteira area is more conserved, with a more closed canopy and between temporary streams, with the characteristics of a mature forest, which provided greater seed accumulation. In addition to that, the Serra Branca has a steep slope and rocky terrain, which interfere with the accumulation of dead plant biomass (necromass). Moreover, in this environment, there is a greater accumulation of leaves and branches, with the presence of recalcitrant components that cause a low decomposition rate in the semi-arid environment (Almeida et al., 2020) and, consequently, do not favor seed germination.

In the collection of plant litter, the presence of leaves was greater than in deeper layers (topsoil), which compromises seed germination, and only a few species manage to germinate and establish themselves due to their low tolerance. Moreover, if these seeds find favorable conditions to germinate, they are not able to re-establish themselves for a long time because they lose their viability very quickly and die, even those late species that remain for a year in the seed bank (Miranda Neto et al., 2020).

The locations with altitudes and steeper slopes have a large volume of plant litter and consequently high species richness (Almeida et al., 2020). However, the Serra Branca collection environment had an altitude of up to 700 m, higher than Pimenteira, and showed lower species richness (Figure 3B). In the Pimenteira area, there are temporary rivers that provided greater species richness because, in places closer to watercourses, there is greater species diversity due to water availability (Farias et al., 2016).

Both seed bank techniques showed favorable seed germination, although the seeds were taken from the dry forest of the Caatinga domain and placed in degraded areas without specific management or irrigation. The number of seedlings in the plant litter seed bank was 53 individuals, distributed among 12 families and 25 botanical species (Table 1), and in the topsoil, there were 142 individuals, distributed among 18 families and 36 species.

Table 1. Survey of species from the seed bank (plant litter and topsoil), introduced in degraded areas of UFRPE/UAST. Serra Talhada/PE, 2018. Font: Saraiva et al. (2021).

Family	Species	H	Plant litter		Topsoil	
			SB	P	SB	P
Amaranthaceae	*Alternanthera brasiliana* (L.) Kuntze	Her	-	-	1	-
Anacardiaceae	*Myracrodruon urundeuva* Allemão	Tr	-	1	11	8
Asteraceae	*Blainvillea biaristata* DC.	Sub	-	-	1	-
	Centratherum punctatum Cass.	Her	-	2	2	2

	Vernonia chalybaea Mart. ex DC.	Sub	-	-	-	1
Boraginaceae	*Euploca procumbens (*Mill.) Diane & Hilger	Sub	-	-	3	-
Burseraceae	*Commiphora leptophloeos* (Mart.) J. B. Gillett	Tr	-	-	1	5
Convolvulaceae	*Evolvulus glomeratus* Nees & Mart.	Sub	-	1	-	-
	Jacquemontia evolvuloides (Moric.) Meisn.	Clim	-	1	-	-
	Ipomoea sp.	Clim	-	-	-	3
	Ipomoea nil (L.) Roth	Clim	1	-	3	-
Euphorbiaceae	*Alcalypha poiretii* Spreng.	Her	-	1	-	22
	Bernardia sidoides (Klotzsch) Müll. Arg.	Her	-	1	-	-
	Croton hirtus L'Hér.	Her	-	-	13	-
	Croton sp.	Sh	-	-	-	1
	Croton glandulosus L.	Sub	1	-	-	-
	Euphorbia hyssopifolia L.	Her	-	4	-	1
	Manihot carthagenensis (Jacq.) Müll. Arg.	Tr	-	-	1	-
Lamiaceae	Indeterminada	-	-	3	-	-
Leguminosae	*Ancistrotropis peduncularis* (Kunth) A. Delgado	Clim	-	-	-	1
	Centrosema brasilianum (L.) Benth.	Sub	1	-	-	-
	Chamaecrista pilosa var. luxurians (Benth.)	Sub	1	-	-	-
	Desmodium glabrum (Mill.) DC.	Her	-	-	-	4
	Indigofera suffruticosa Mill.	Her	2	-	-	-
	Macroptilium sp. (Benth.) Urb.	Clim	-	1	-	-
	Senna macranthera (DC. ex Collad.)	Tr	-	-	1	-
Loasaceae	*Mentzelia aspera* L.	Her	-	-	-	7
Loganiaceae	*Spigelia anthelmia* L.	Her	2	-	-	-
Lythraceae	*Cuphea circaeoides* Koehne	Her	-	-	-	2
Malpighiaceae	*Galphimia brasiliensis* (L.) A. Juss.	Sub	-	-	1	-
Malvaceae	*Corchorus argutus* Kunth	Sub	-	1	-	-
	C. hirtus L.	Her	-	-	-	1
	Herissantia crispa (L.) Briz.	Sub	1	4	1	-
	H. tiubae (K.Schum.) Brizicky	Sub	-	-	7	-
	Sida sp.	-	1	1	3	-
	Indeterminada	-	-	1	-	-
Molluginaceae	*Mollugo verticillata* L.	Her	3	4	2	-
Oxalidaceae	*Oxalis cratensis* Hook.	Her	-	1	-	-
	O. glaucescens Norlind	Her	-	2	-	-
Phyllanthaceae	*Phyllanthus* sp.	Her	-	-	-	1
Phytolaccaceae	*Microtea paniculata* Moq.	Her	-	-	-	2
Poaceae	Indeterminada 1	Her	-	-	2	6
	Indeterminada 2	Her	-	-	-	5
	Indeterminada 3	Her	-	-	-	2
	Indeterminada 4	Her	-	-	3	-
	Indeterminada 5	Her	-	-	-	2
Portulacaceae	*Portulaca halimoides* L.	Her	-	1	-	-
	P. hirsutissima Cambess.	Her	3	-	-	-
	P. oleracea L.	Her	-	-	3	1
Rubiaceae	*Richardia brasiliensis* Gomes	Her	3	2	1	1
	Mitracarpus sp.	Her	-	2	-	-
Indivíduo 1	NI	-	-	-	-	1
Indivíduo 2	NI	-	-	-	3	-
Total of individuals			53		142	

H = Habit (Tr = tree, Sh = shrub, Her = herbaceous plant, Sub = subshrub, Clim = climbing plant); SB = Serra Branca; P = Pimenteira; NI = Unidentified.

The most expressive life form of the species found was herbaceous, both in the plant litter seed bank (61%) and in the topsoil (63.25%) (Table 1). This type of predominant life form is due to its permanence in the soil for a longer time, in conditions of intermediate stages of regeneration (Kunz & Martins, 2016), as found in the two collection areas, and by the type of soil fertility (Rodrigues et al., 2010). Herbaceous plant seeds can undergo dimorphism (aerial and subterranean seeds) and physical dormancy, which makes them efficient for survival in the face of the uneven climatic conditions in this ecosystem (Souza et al., 2020). They help in the interpretation of the resilience of this ecosystem, which is why they were not excluded from the accounting for species density.

The *A. poiretii* species was the most abundant, especially in the Pimenteira area (Table 1 and Figure 4), but it is more common to find it in more disturbed ruderal areas and in open vegetation (Sousa et al., 2017), which does not characterize this area that is less disturbed and has a more closed canopy. However, the Pimenteira area is between temporary streams, which favored the number of viable seeds in this environment, with higher species richness and diversity (Lima et al., 2013).

The second abundant species found was *C. hirtus*, which also occurred in the topsoil (Table 1 and Figure 4), but in the Serra Branca environment, where it is very common to find it (Melo et al., 2013), in poor and stony soils.

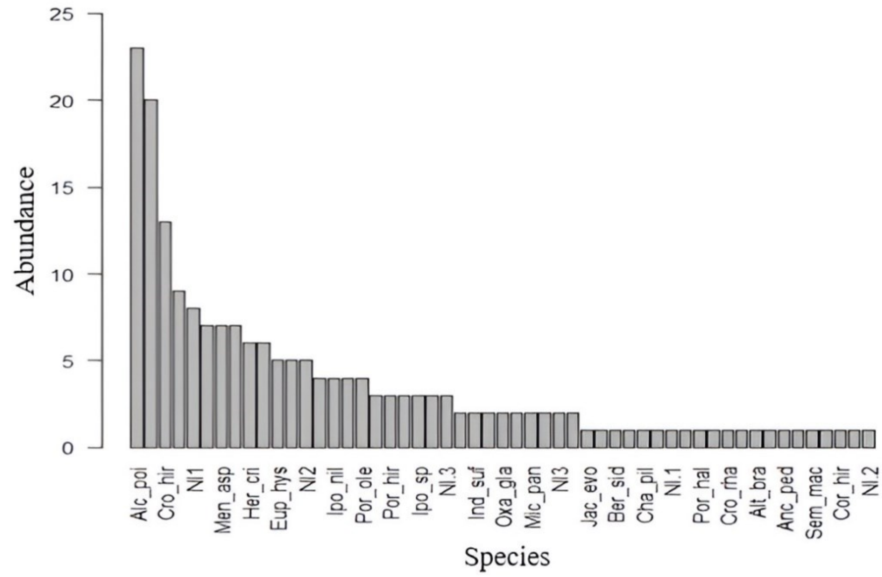

Figure 4. Abundance of species counted by Whittaker, in the plant litter and topsoil seed bank in the environments (Pimenteira and Serra Branca) of the Mata da Pimenteira State Park Serra Talhada-PE, in 2018. Alc_poi (*Alcalypha poiretii* Spreng.), Cro_hir (*Croton hirtus* L'Hér.), NI1 (Indeterminada 1), Men_asp (*Mentzelia aspera* L.), Her_cri (*Herissantia crispa* (L.) Briz.), Eup_hys (*Euphorbia hyssopifolia* L.), NI2 (Indeterminada 2), Ipo_nil (*Ipomoea nil* (L.) Roth), Por_ole (*Portulaca oleracea* L.), Por_hir (*P. hirsutissima* Cambess.), Ipo_sp (*Ipomoea* sp.), NI.3 (Indivíduo não identificado 2), Ind_suf (*Indigofera suffruticosa* Mill.), Oxa_gla (*Oxalis glaucescens* Norlind), Mic_pan (*Microtea paniculata* Moq.), NI3 (Indeterminado 3), Jac_evo (*Jacquemontia evolvuloides* (Moric.) Meisn.), Ber_sid (*Bernardia sidoides* (Klotzsch) Müll. Arg.), Cha_pil (*Chamaecrista pilosa* var. luxurians (Benth.), NI.1 (Unidentified. 1), Por_hal (*Portulaca halimoides* L.), Cro_rha (*Croton* sp.), Alt_bra (*Alternanthera brasiliana* (L.) Kuntze), Anc_ped (*Ancistrotropis peduncularis* (Kunth) A. Delgado), Sen_mac (*Senna macranthera* (DC. ex Collad.), Cor_hir (*Corchorus hirtus* L.) e NI.2 (Unidentified). Font: Saraiva et al. (2021)

To better explain the ecological context and conservation of the species found in the two environments, the species dominance diagram was applied to each technique and collection environment analyzed (Figure 5). Both techniques (Figure 5A) showed a steeper gradient, with low uniformity and high species abundance, but for the topsoil technique, the curve was longer due to the higher number of individuals found (Table 1) and higher species richness (Figure 3A), relative to the plant litter. However, the plant litter showed less equability (a steeper curve), which represents less uniformity among the species found. Thus, both techniques have the potential for the conservation of species in other degraded areas. However, for the conditions of the Caatinga ecosystem, the topsoil became more efficient because of the quantity of permanently viable seeds in the soil.

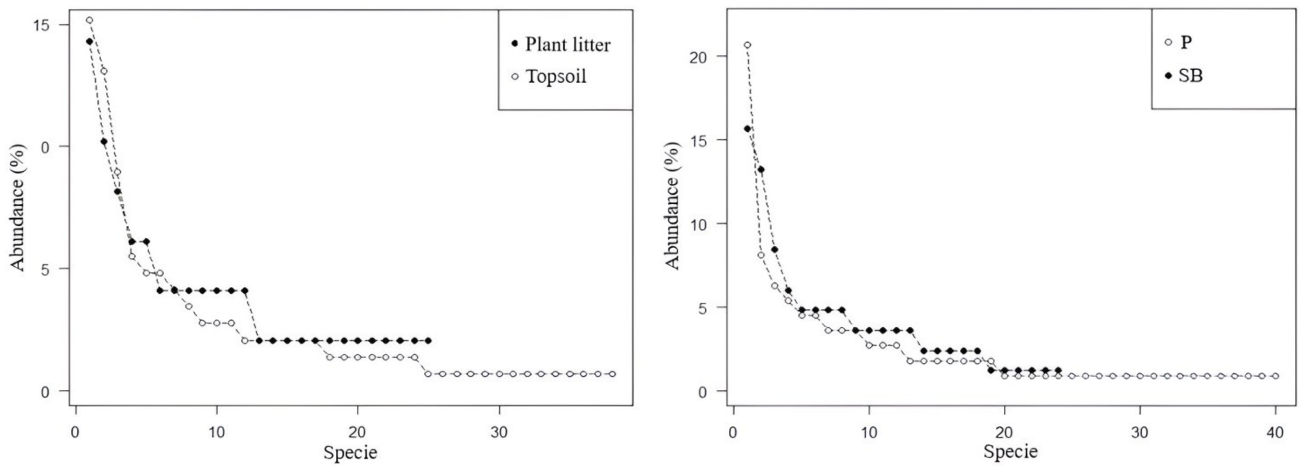

Figure 5. Species abundance curve or Whittaker, distributed across seed bank types. (A). Collection sites in the environments; (B). Mata da Pimenteira State Park Serra Talhada-PE, in 2018. Font: Saraiva et al. (2021).

The two collection environments proved to be excellent for soil transposition, as they showed steep gradients and lower equability (Figure 5B). However, the Pimenteira environment has a greater potential for viable seed banks for application in restoration projects in degraded areas, especially when using the nucleation method, which consists of the formation of small nuclei that aim to elaborate microhabitats that favor the process of natural regeneration using materials that enable interaction among organisms in a successional way.

Conclusions

The topsoil technique can be used in semi-arid conditions because it obtained a faster emergence of seedlings and greater species richness, especially in the seed bank of a more preserved environment such as the Pimenteira of the Pimenteira State Park, with the species *Alcalypha poiretii* Spreng. and *Myracrodruon urundeuva* Allemo.

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