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Post-logging regeneration and recruitment of shihuahuaco (*Dipteryx* spp.) in Peruvian Amazonia: Implications for management

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ABSTRACT

Over the past decade, shihuahuaco timber – comprising several species of *Dipteryx* (Fabaceae) traded internationally as "cumarú" or "Brazilian teak" – has become one of the most highly demanded types of hardwood from Peruvian Amazonia, particularly in the Chinese market. *Dipteryx* is an ecologically important canopy-emergent genus with widespread distribution in neotropical forests. To assess the response of *Dipteryx* to logging, we conducted inventories in three logging areas in the Regions of Ucayali and Loreto, Peru. The size-class distributions of *Dipteryx* populations in recently logged sites showed that initial post-logging conditions enhance recruitment of residual seedlings. These conditions are created by a combination of logging gaps and the activities of farmers migrating into logged lands. Through protection and liberation of shihuahuaco seedlings in post-logged forest as well as within and around agricultural fields, local residents and timber companies could favor the recovery of this valued resource. However, as logged land is increasingly converted to agriculture and pastureland, the reestablishment of mature seed trees is not assured.

1. Introduction

Logging pressure on traditional high-valued Amazonian hardwoods such as big-leaf mahogany (*Swietenia macrophylla*) and tropical cedar (*Cedrela odorata*) has threatened supplies as well as the regeneration of these species over much of their natural range (Navarro et al., 2003; Snook et al., 2003; Grogan et al., 2005; Grogan and Barreto, 2005; Muellner et al., 2009). Over the past decade, in part due to the increased scarcity and legal protection of these species, growing global demand for tropical hardwoods has resulted in a diversification of internationally traded Amazonian timber species (ITTO, 2008) and spurred the expansion of logging into new areas (Schulze et al., 2008a,b). One recently studied example of this phenomenon is îpe (*Tabebuia* spp.), an Amazonian hardwood that has been endangered by an extractive boom, especially in Brazil but also Peru and other countries (Schulze et al., 2008b).

Similarly, several species of *Dipteryx*, collectively known in Peru as shihuahuaco and internationally traded as "cumarú" or "Brazilian teak", have for the past several years been the target of an extractive boom. Like îpe, shihuahuaco is valued for its high wood density and resistance to rot, making it ideal for outdoor applications such as decking and patio furniture, for which it is used in North America and Europe. However, due to the growing dominance of Chinese timber companies and exporters in Peru, the majority of extracted Peruvian shihuahuaco is shipped to China to provide raw material to that country's huge domestic and global flooring market (Putzel et al., 2008). In 2008, shihuahuaco represented nearly half of Peru's timber exports; of that approximately 80% was shipped to China (Putzel, 2010).

While in terms of their particular value for outdoor uses îpe and shihuahuaco might be considered as alternatives to teak (*Tectona grandis*), their supply has not been supplemented, as has that of teak, by extensive plantation production (but see Montagnini, 2001; Romo, 2005). Rather, the future of these species thus far depends on their natural regeneration potential in post-logged forests. Schulze et al.'s (2008b) study of the population-level and broader impacts of îpe logging in Brazil found that recovery of populations without protection is unlikely and that the targeted logging of îpe is a likely catalyst for forest colonization and conversion to agriculture.

The objective of this study is to provide insights into the population-level effect of increased logging of another important Amazonian timber resource and to present some potential implications for management. Over the past 15 years, in response to demand from the Chinese timber market, shihuahuaco has gone from virtual anonymity to boom time species; however,

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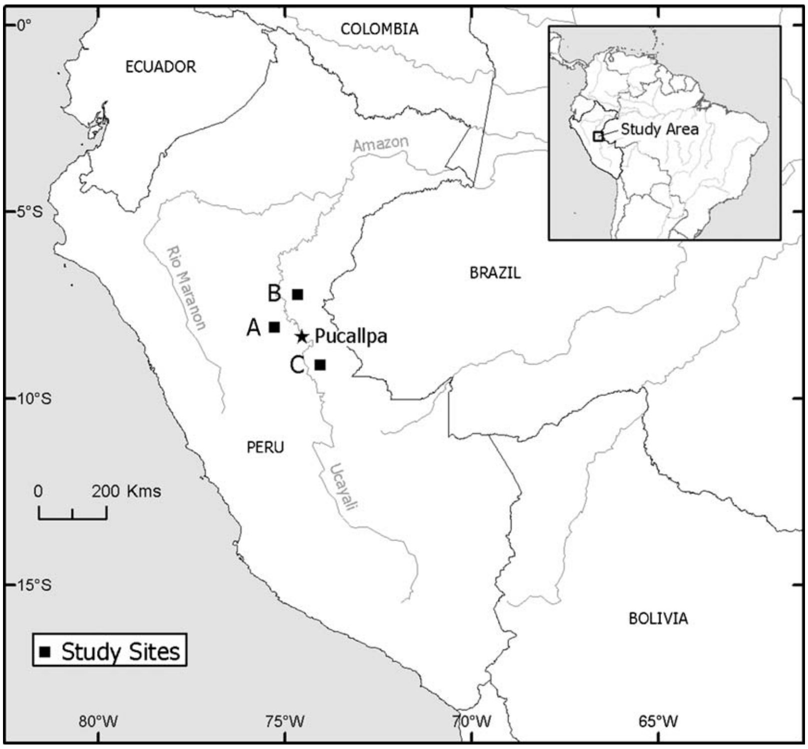

Fig. 1. Map of study areas centered around Pucallpa, Peru with location of logging zones near Neshuya (A), Iparia (B), and Contamana (C). Of these, Neshuya is accessible by road, while Iparia and Contamana are only accessible via the Ucayali River. All areas were previously selectively logged at least once in the 1980s, before there was a market for shihuahuaco timber.

the response of populations to logging activities is not yet well understood. We conducted a field study of the regeneration and recruitment response of shihuahuaco populations in three logging areas centered around Pucallpa, Peru's largest timber milling center, based on which we make a number of observations of potential use in managing for future timber stocks.

2. Shihuahuaco species description

Dipteryx spp. trees are widespread neotropical canopy-emergents of up to 150 cm dbh (diameter at breast height) and 35–60 m in height (Terborgh and Wright, 1994; Reynel et al., 2003). Their large mass is supported by broad buttresses, making them ecologically important both for the structural integrity they add to the forest while standing (Clark and Clark, 2001) and also for the large gaps they leave when they fall, facilitating successional forest growth (Romo et al., 2004b). Research on *Dipteryx panamensis*, a close relative of shihuahuaco, suggests that, at least in natural forest conditions, species of this genus are extremely slow growing, with an estimated median age of 72 years for understory juveniles measured at 4 cm dbh (Clark and Clark, 2001; Romo and Tuomisto, 2004). Maximum adult ages of 330 years (*D. panamensis*) and 1000–1200 years (*D. odorata*) have been estimated (Clark and Clark, 1992; Chambers et al., 1998; Romo and Tuomisto, 2004).

The plentiful, large (3–4 cm) seeds mature in the dry season, providing an important source of food for many species, including bats and other herbivorous mammals such as agoutis, peccaries, deer, and tapir (Terborgh and Wright, 1994; Romo et al., 2004a). In addition, shihuahuaco trees are important nesting sites for several species of parrots and macaws, leading Brightsmith (2005) to refer to shihuahuaco as a “keystone tree”; communities of these birds may use individual trees for decades or centuries. Frugivorous bats that feed on the fleshy mesocarp of shihuahuaco fruit disperse the seeds in deposits located away from parent trees. Bat seed deposits are evident, often appearing under palm leaves where bats rest while feeding and near the edges of open forest pathways that facilitate their movement through the forest (Romo et al., 2004a,b).

With its large seeds and shade-tolerant seedlings, shihuahuaco trees regenerate in both late-successional and mature forest and a variety of habitats, from floodplain to upland forests. While shade tolerant at seedling and sapling phases, they require light to grow into the larger size-classes. Medium sized trees (poles, juveniles) have been found to occur in very low densities in natural unlogged conditions compared to other size classes (Romo et al., 2004b).

There are two species of *Dipteryx* prevalent in the study area: *D. micrantha* and *D. alata*. These correspond roughly to two types commonly recognized by local woodsmen – *shihuahuaco rojo* and *shihuahuaco amarillo*, respectively – differentiated according to the color of the bark, size of the leaves, and color of the wood. Some woodsmen also recognize a type known as *shihuahuaco negro*, however this may be a variety of *D. micrantha*. A third species, *D. odorata*, which occurs over a large area of Amazonia and has been identified in both northern and southern Peruvian Amazonia, does not appear to be present in the study region, despite the common use of the name in local commercial forest inventories and export documents. Further systematic work on *Dipteryx* is called for, because the genus has not been revised since Ducke's 1940 revision (Ducke, 1940). For this reasons, this study is a genus-level study of Peruvian *Dipteryx* bearing the common name shihuahuaco.

3. Methods

3.1. Study sites

Three active logging zones, which we refer to by the names of nearby settlements (Fig. 1) were identified through meetings with logging company personnel based in the mill-town of Pucallpa. The first, near the village of *Neshuya*, is centered around a 40,000 ha timber concession accessible from km 60 of the Federico Basadre Highway, linking Pucallpa to Peru's road network. Now being

Table 1
Sampling areas, location, and logging history. All areas were logged in 1980s for mahogany and cedar. In the Neshuya and Iparia study zones, selective logging had been newly conducted, respectively, 2–4 and 1–2 years prior to our inventories.

Zone	Province, region	Total sample area (ha)	Seedling sub-sample area (ha)	Logging history
A. Neshuya	Coronel Portillo, Ucayali			
Old-logged		6.96	0.73	1980s
Recently logged		9.82	1.96	1980s, 2–4 years prior
B. Iparia	Coronol Portillo, Ucayali			
Old-logged		4.50	0.90	1980s
Recently logged		3.50	0.70	1980s, 1–2 years prior
C. Contamana	Ucayali, Loreto			
Old-logged		4.00	0.80	1980s
Total		29.00	5.13	
Total old-logged		14.96	2.33	
Total recently logged		14.04	2.80	

logged by the company that owns the concession, a number of other extractive companies have also held contracts to log the concession and private lands in surrounding communities. The second, near *Iparia*, is a production forest and surrounding private landholdings accessible via the Ucayali River located approximately 100 km south of Pucallpa. There, a Pucallpa-based logging company is active. The third is a grouping of private landholdings located near the town of *Contamana* on the Ucayali River approximately 125 km north-northwest of Pucallpa, now also being logged by a different Pucallpa-based timber company. Interviews with logging company personnel and local woodsmen indicated that all zones were selectively logged for mahogany, cedar, and in the case of Contamana, tornillo (*Cedrelinga catenaeformis*) during the 1980s. According to local woodsmen, these forests were not previously logged for shihuahuaco.

Each of these zones is located on the edge of hilly or mountainous formations, and is in the process of being converted, to varying degrees, to a mixed agricultural and fragmented forest landscape. Current logging activities in these zones started 0–4 years prior to this study. For convenience and ease of reading, sites recently logged will be referred to as "recently logged" and sites logged more than 20 years prior to the study will be referred to as "old-logged."

Neshuya and Iparia, which contained both old-logged and recently logged forest, were suitable for comparative studies, while logging in our Contamana zone had just begun in 2008 and therefore at the time of study there were no sites suitable for inventories of recently logged forest. Recently logged study sites in Neshuya were selectively harvested between 2 and 4 years prior to the study, while recently logged study sites in Iparia were harvested between 1 and 2 years prior to the study. In all zones, timber companies logging the concession and private parcels are in competition with local residents for the shihuahuaco resource: in addition to being logged by industrial operations shihuahuaco is artisanally extracted and sold in "predimensioned" forest-chainsawed blocks called *cuartones* to sawmills in Pucallpa or Contamana, where it is sized for parquet flooring. In Neshuya, local residents also cut entire trees for charcoal which is bought by truckers and delivered to the market in Lima, from where some of it is reportedly exported to Asia.

3.2. Sampling and measurements

Regeneration studies were carried out in old-logged areas of Neshuya, Iparia and Contamana, and in recently logged areas of Neshuya and Contamana. Inventories of all individuals ≥50 cm in height were conducted using a systematic sampling method (see e.g. Schreuder et al., 1993) with 10 m × 20 m plots arranged in parallel transects for total inventory areas of 14.96 ha of old-logged and 14.04 ha recently logged forest. Seedlings less than 50 cm in height were subsampled in 2 m-wide transects central to the above-mentioned 10 m-wide transects. Individuals of smaller size-classes were classified according to their proximity to adult seed trees, watercourses, and treefall gaps in order to test the potential importance of seed dispersal patterns and location to post-logging regeneration and recruitment. Individuals located within the crown shadow of an adult, by best estimate, or within 5 m of a water course or treefall gap – established by running a pre-measured cord from the individual to the feature – were classified (Table 1).

Shihuahuaco individuals were assigned to six size classes: seedlings (<50 cm in height), saplings 1 (≥50 cm in height and <1 cm diameter), saplings 2 (≥1 cm diameter and <4 cm diameter), poles (≥4 cm in diameter and <10 cm in diameter), juveniles (≥10 cm and <40 cm in diameter) and adults (≥40 cm in diameter). All measurements of diameter were at breast height (dbh) for all individuals > 150 cm in height; diameters of individuals < 150 cm in height were taken at the base of the stem. Seedlings were divided into two categories: 0 year seedlings (<1 year since germination) and 1+ year seedlings (more than 1 year since germination). In Neshuya, inventories were conducted during the germination season in August, and numbers of 0 year seedlings are reported separately from all other results, which exclude 0 year seedlings.

In the case of large-buttressed adults, diameter was estimated based on the consensus of three observers. Height of individuals <5 m was measured using a meter tape and of individuals >5 m and <8 m using a pole. Depending on the visibility of the crown of each sample trees, height was either estimated or measured using a clinometer. For saplings >1 cm in diameter and for poles, the number of times the apical meristem had been broken was estimated by counting the number of evident breakage scars, characterized by a knobby protrusion, on each stem.

In a second study, conducted in the study zone near Neshuya, nine permanent 10 m × 20 m plots were delimited to study seedling growth and survivorship from year 1 to year 2. Three plots containing seedlings aged one year or more ("1+ year seedlings") were located in undisturbed forest, three plots containing 1+ year seedlings were located in disturbed forest, and three plots containing seedlings younger than one year ("0 year seedlings") were located in logging skidtrails.

4. Results

4.1. Size class distributions and differential growth rates of individuals in old-logged vs. recently logged forest

The observed average density of adults of all species of shihuahuaco in 33 ha of transects was 1.15 trees per ha ($n = 38$). This

Table 2
Per-hectare occurrence of shihuahuaco individuals by size class in sites in Neshuya, Iparia, and Contamana, presented by logging history. Table excludes new seedlings, which were only counted in Neshuya, and plots in which seedlings were not counted, also in Neshuya, unlogged since 1980s ("old-logged"). In recently harvested zones, "adult" refers to felled trees, shown here in parentheses to relate to residuals of other size classes. The italicized numbers in parentheses are the standard errors of the numbers of individuals occurring in all 10 m × 20 m plots by zone and logging status.

Size class	Logged >20 years prior							Recently logged				
	A. Neshuya		B. Iparia		C. Contamana		Mean	A. Neshuya		B. Iparia		Mean
Seedlings	9.6	(.22)	33.5	(.60)	21.3	(.70)	22.3	2.5	(.25)	7.1	(.26)	3.8
Saplings 1	0.8	(.05)	5.8	(.18)	2.8	(.09)	3.3	5.1	(.34)	17.7	(.30)	8.4
saplings 2	0.8	(.05)	4.5	(.15)	3.3	(.12)	3	17.2	(.52)	6.9	(.15)	14.5
Poles	0	(n/a)	0.4	(.04)	0	(n/a)	0.2	1.5	(n/a)	0.3	(.03)	1.2
Juveniles	0.3	(.03)	0	(n/a)	0.3	(.03)	0.2	0.4	(.06)	0.9	(.05)	0.5
Adults	1.4	(.06)	0.9	(.06)	1.5	(.07)	1.2	−1.8	(.12)	−0.6	(.04)	−1.5

figure includes, in recently logged zones, stumps of felled trees (n = 19). Of the 26 trees (standing and felled) where identification was possible, roughly 42% were identified as *shihuahuaco amarillo* and 54% as *shihuahuaco rojo*, with one individual identified as *shihuahuaco negro*. In recently logged zones, 18 trees had been felled, one was left standing, and one had fallen naturally.

A comparison (Table 2) of size classes between all old- and recently logged sites revealed a difference in regeneration and recruitment patterns. The old-logged distribution is an inverse-J shaped or negative exponential distribution typical of many shade tolerant tropical forest trees (see, e.g. Peters, 1995; Meyer, 1952), with high ratios of seedlings to saplings, saplings to poles, poles to juveniles and a low ratio of juveniles to all other size classes. The recently logged distribution shows a decrease in the proportion of seedlings to saplings, and an increased proportion of poles and juveniles (Fig. 2).

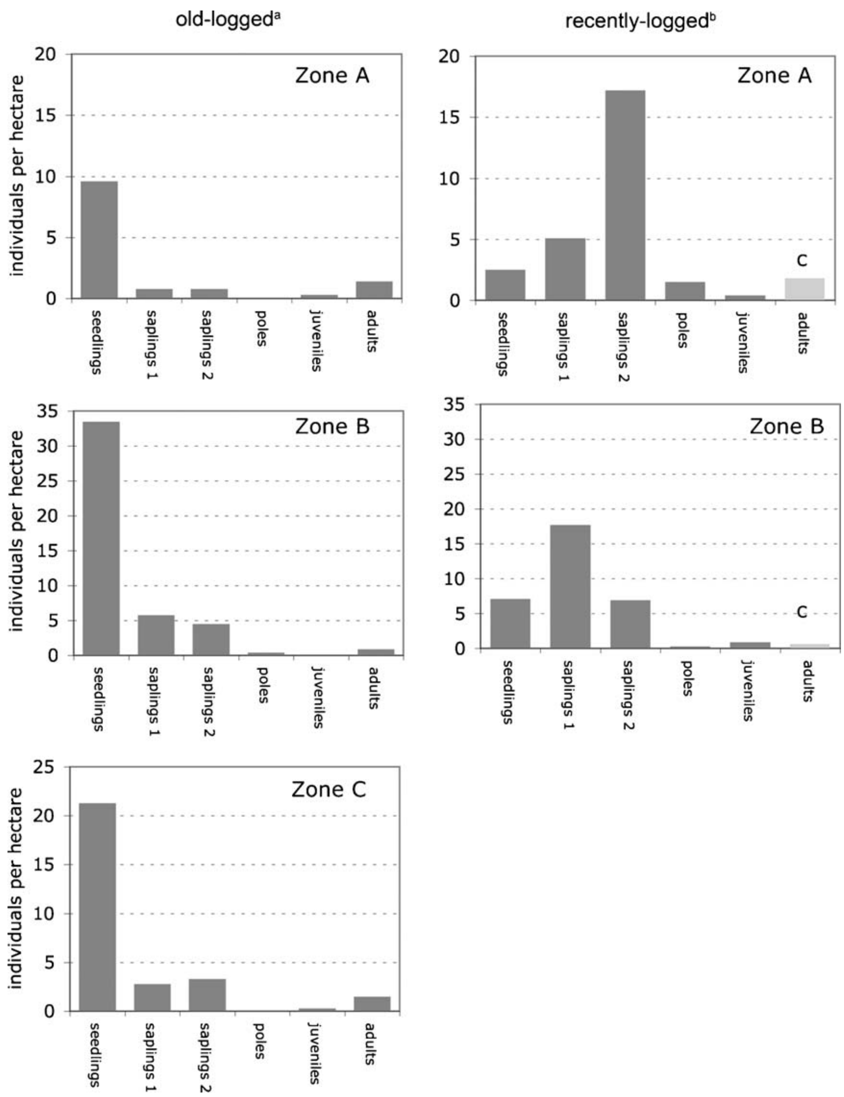

Fig. 2. Shihuahuaco size-class distributions observed in old-logged and recently logged sites in three study zones in Ucayali and Loreto regions. (a) Forest termed "old-logged" was selectively highgraded for mahogany and cedar in 1980s. Shihuahuaco was left standing at that time, (b) forest termed "recently logged" was logged for multiple species, including shihuahuaco, 2–4 years prior to study (zone A) and 1–2 years prior to study (zone B) and (c) adult category in recently logged sites reflects pre-logging density as ascertained by stump identification; shown for comparative purposes.

Table 3
Permanent plots – growth and survival in undisturbed (<5% canopy open) vs. disturbed (5–10% canopy open) forest.

		Understory 1+ year seedlings	Gap edge 1+ year seedlings	Disturbed soil new seedlings
Height (cm)	2007	36.6	39.7	20.7
	2008	37.0	46.2	42.0
Change (cm)		0.3	6.5*	21.3*
Change (%)		0.8	16	102
p value		0.8496	<.0006*	<.0001*
F-ratio		0.036	12.234	171.091
Number	2007	36	130	56
	2008	23	75	43
Mortality		36%	42%	23%

In a one-way ANOVA, mean height of combined seedlings and saplings was significantly higher ($p < 0.0001$) in recently logged zones (195.9 cm, $n = 315$) than in old-logged zones (101.3 cm, $n = 130$). Among zones, there was no significant difference in old-logged height of these size classes. In recently logged sites, however, mean height varied significantly from 227.7 cm in Neshuya ($n = 224$) to 117.6 cm in Iparia ($n = 91$) ($p < 0.0001$). This difference corresponds to the already mentioned tendency of the distribution of individuals in Neshuya towards larger size classes as residual seedlings are recruited.

Height of seedlings in all sites (old- and recently logged) was significantly associated with their location in relation to treefall gaps. In particular, the mean height of seedlings located within 5 m of gaps ($n = 34$) was 17% taller ($p < 0.0001$) than seedlings located under closed or partially open canopy or in full gaps. In recently logged sites, 35% of inventoried seedlings were located within 5 m of gap edges, compared to only 3% in old-logged sites, which reflects the comparative abundance of gaps in recently logged forest.

Of all seedlings, saplings and poles observed, 17% were located within 5 m of a stream or streambed, while only 8% of plots were crossed by streams. Eighteen percent were located in the crown shadow or in the case of recently logged areas, the former crown shadow of a shihuahuaco adult, representing only 3% of plots surveyed.

In recently logged areas, a subset of saplings >1 cm diameter and poles showed evidence of having been broken an average of 2.3 times, compared to 1.2 times in the case of old-logged areas ($p = 0.0026$). A nested ANOVA to ascertain whether this effect was related to a greater diameter size in recently logged areas showed that the estimated number of times individuals were broken did not significantly relate to diameter.

4.2. Permanent plot data – growth and mortality of seedlings in understory, gap edge, and disturbed soil conditions

In permanent plots visited in 2007 and 2008, seedling growth varied depending on conditions created by logging (Table 3). In low light understory conditions where the canopy had not been disturbed, established seedling height ($n = 36$) did not increase significantly between 2007 and 2008. In higher light conditions near newly created gap edges, on the other hand, established seedlings ($n = 130$) grew an average of 6.5 cm, an increase of 16% over the 1 year period. In plots containing new seedlings that germinated in 2007 in skidtrails where the soil had been substantially disturbed, seedling height increased an average 21.3 cm, or 102% over the 1 year period.

Seedling mortality from year to year was not significant, though some reflection on the potential relationship of the numbers to observed conditions may yield several hypothetical explanations. Plots located in the understory showed no apparent change from 1 year to the next. Undergrowth in these plots was minimal, and the seedlings were located in low-undergrowth conditions overtopped by the canopy many meters above. It is therefore likely that the 36% mortality rate of these seedlings ($n = 36$) can be explained by a gradual failure of individuals due to insufficient light. In the gap edge conditions, on the other hand, two factors might explain the slightly higher mortality (42%, $n = 130$). The first was the fact that a large tree branch had fallen onto one of the plots, destroying many seedlings. Another likely factor is that in the enhanced light conditions of the gap edge, competition among seedlings and with weedy plants was high. Finally, in the plots containing new seedlings growing on disturbed soil ($n = 56$, mortality = 23%), as compared to gap edges, the establishment of competitors was temporarily limited by the removal of the top soil layer, allowing seedlings to germinate and grow quickly with little competition. By the end of the first year, competing pioneer species were well on the way to interfering with the new seedlings, which, over the next year are expected to increase the mortality rate of this group.

5. Discussion

The configurations of shihuahuaco size-class distributions obtained from our inventories in old-logged forest in zones A, B, and C are similar to results of previous research conducted in unlogged forest in Madre de Dios (Romo et al., 2004b).

A clear difference in shihuahuaco regeneration and recruitment patterns was detected between areas that were recently logged and areas which had been relatively undisturbed for the past 20 years, and which had never been logged for shihuahuaco. As might be expected due to the removal of mature seed-producing trees, seedling abundance was lower in recently logged areas, and furthermore in comparison of sites logged 1–2 years prior and 2–4 years prior, appeared to follow a declining trajectory over time. However, a concurrent phenomenon of enhanced recruitment to sapling and pole size classes was apparent, and also associated with time since logging.

In comparing the size distributions between zones, the distinction between old- and recently logged configurations was maintained, with some interesting inter-site variations. Most evident was the overall lower count of individuals in old-logged Neshuya plots compared to Iparia and Contamana, however, all configurations were consistent with an inverse-J curve. In recently logged sites, the shape of the distribution tends towards larger size classes (saplings and poles) in Neshuya, where more time had elapsed since logging, than in Iparia, which had significantly more seedlings and a more even distribution between seedlings and saplings.

Based on our data, the density of saplings (1–4 cm diameter) in recently logged conditions might increase as much as 20 times compared to that in old-logged conditions. This has important management implications, because as noted in earlier studies *Dipteryx* saplings over 1 cm in diameter with well established roots have a high likelihood of survival (Romo, 2005; Clark and Clark, 1987).

Shihuahuaco regeneration is especially concentrated in two particular microenvironments associated either with streams, which have been associated with the movements and feeding behaviors of bat species that feed on shihuahuaco fruit and have more light, or where seeds accumulate under the crowns of adult trees. In, Cocha Cashu and other forest in Manu, the densities of seedlings, saplings and adults were also higher close to forest margins of lakes, rivers and streams than in other sites of the mature forest (Romo et al., 2004b).

Our data support the hypothesis that shihuahuaco seedlings perform best in the understory near gap edges, as proposed by Romo and Tuomisto (2004), and these conditions are more common in recently logged areas. Unlike previous studies in Cocha Cashu, however, which found few seeds located under mature trees, in our study sites we counted a disproportionate number of seedlings under parent trees, and observed the frequent presence of seeds under adults during the fruiting season. This may be explained by a relative lack of seed predators due to hunting in logging zones. Given these factors, it is logical to expect enhanced survivorship and growth of residual seedlings located near the edges of a gap created by the felling of a conspecific adult, where such seedlings might not survive in the crown shadow of a standing tree.

In recently logged sites, the lower number of seedlings is explained by the removal of adult seed trees. However, the greater number of saplings and especially poles and juveniles in those areas indicates higher rates of recruitment in recently logged areas with different light conditions. Furthermore, our examination of breakage scars and juvenile diameters suggests that, while logging (and potentially post-logging disturbances) results in a higher frequency of stem breakage, breakage does not necessarily result in greater mortality once individuals have reached a certain size. This finding is potentially significant in terms of the resilience of *Dipteryx* spp. to logging activities. In the right light conditions, and especially if protected from pioneer competitors, these species are likely to recover even if subjected to repeated disturbances.

As noted throughout Amazonia, timber harvesting activities are followed by settlement by smallholders who make use of logging roads and gaps to engage in agricultural activities (see, e.g. Asner et al., 2005, 2006). We observed this phenomenon in all our study zones, including those surrounding old-logged forest, and human activity in recently logged areas was apparent. For example, a number of gaps encountered in recently logged areas had been used to make charcoal or to salvage viable wood from large branches and stumps left by extractive teams. There was evidence as well of the slashing of undergrowth throughout the forest, indicating the regular presence of people. Additionally, local farmers recognize and are likely to spare shihuahuaco seedlings during their movements and small scale clearing activities (i.e. those that fall short of field and pasture creation through burning). The creation of more gaps through harvesting as well as the nature of initial human activities in recently logged areas may well enhance the conditions for recruitment of shihuahuaco from residual seedlings to higher size-classes.

Although the Peruvian Forest Law requires that timber management plans, a precursor to obtaining permits to cut and transport timber, identify a percentage of seed trees to be spared in order to facilitate natural regeneration, in the case of shihuahuaco it is unlikely that any accessible mature tree will survive logging and the post-logging activities of local people. We observed that, during logging, even trees that are found to be completely hollow, and thereby useless for timber, are cut because they are extremely useful as culverts to channel the water of streams under logging roads, which are continuously extended during harvest operations. Besides the extraction of logs by logging companies, there is an informal market for chainsawed *cuartones*, which are small enough (ca. 1 m × 20 cm × 20 cm) to hand carry out of the forest. Additionally, because shihuahuaco provides the highest quality charcoal in the market, during and following logging booms, a secondary shihuahuaco charcoal boom results in the cutting of even submarketable timber trees (Pers. Obs.).

Although the reforestation of logged concession areas by timber companies is legislated in the Forest Law, reforestation is rarely undertaken. For economic reasons and through lack of enforcement, the fate of logged areas is left to a combination of natural regeneration and to the beneficial or detrimental activities of local residents who come to occupy and use the landscape. In zone A we observed that local farmers, both within and around the concession area we studied, were actively collecting seeds and replanting shihuahuaco along with several other useful species, in addition to protecting juvenile size-class individuals they encountered in the remnant forest patches around their fields. While some of these farmers had received seedlings from extension programs promoting reforestation of timber trees, others had acted independently and without outside assistance.

While the initial use of logged forest land results in a landscape of remnant forest patches, small agricultural swiddens, and some pasture, there is a progressive trend towards conversion of the landscape for large-scale pastures and plantation-style productive systems. Therefore, although the occupation of post-logged land by small farmers initially may create conditions favorable to the recruitment of shihuahuaco residuals, the long-term maintenance of these conditions is quite uncertain, unless some form of incentive for “family forestry” (see e.g. Nepstad et al., 2004) results in long-term management of productive forestry landscapes by smallholders.

6. Conclusion – management implications

Our results show that while logging of shihuahuaco is likely to reduce or eliminate seed production and future regeneration, the initial post-logging environmental conditions, both natural and anthropogenic, may in fact enhance the potential for recruitment of residuals. Based on that observation, there is the potential to manage for future stocks.

In terms of management, there are several potential remediation strategies worth the consideration of logging companies and policy makers, beyond the legislated maintenance of seed trees and replanting of logged zones. On a biological level, we observed a higher-than-average concentration of juvenile size-class individuals in the vicinity of streams, both quebradas (where bats deposit seeds) and caños, where seeds fallen from fruiting adults are trapped, as well as around the based of mature individuals. During and in the several years after logging activities, protection of these areas combined with occasional management of competitors might greatly enhance the recruitment potential of shihuahuaco residuals. Additionally, considering the low mortality of individuals over 1 cm diameter, it is worth protecting individuals over that size.

On a social level, we observed the common Amazonian phenomenon of land occupation and use by small farmers in recently logged zones, and noted a tendency of some to protect residuals and even engage in small scale replanting efforts, with or without outside encouragement. While further research on land tenure rights, economic tradeoffs vis-à-vis planting slow growing timbers in agricultural systems, and processes of long-term landscape transformation are needed, the recognition and encouragement of such extant activities, both by timber companies and government, might favor the establishment of a future stock of shihuahuaco, as well as other valuable hardwood species.

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