



## Effects of logging on *Virola surinamensis* in an Amazonian floodplain forest

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### Abstract

*Virola surinamensis* is a dioecious timber species of Amazonian floodplain forests. It is threatened by extinction and a priority species in the conservation program of genetic resources with high economic value for Brazil. The present study was aimed to assess the population structure of *Virola surinamensis* and the impact of logging in the estuary region of Brazilian Amazonia. Our data suggest that altering the dioecious population structure by logging likely creates the imbalance of male and female individuals in the population. New policies are needed to protect *Virola* trees with a special regard on reproductive matriarch trees.

**Keywords:** conservation, dioecious trees, logging, recruitment, regeneration, timber extraction

### Introduction

In the estuary of the Amazon River, the nutrient-rich várzea floodplain forests have great socio-economic importance for the human population. The várzeas of the estuary have a long history of human occupation, which is associated with the exploitation of the natural resources, among which logging stands out. *Virola surinamensis* (Rol.) Warb is one of the most valuable, naturally occurring tree species in this ecosystem (Macedo and Anderson, 1993; Barreto *et al.*, 1998; Almeida *et al.*, 2004; Scabin *et al.*, 2011). In the 1980s, wood production of the floodplain forests made up 75% of the total quantity of wood sold in the Brazilian Amazon. *V. Surinamensis* (here after *Virola*) accounted for about 50% of the total volume of extracted wood (Salomão *et al.*, 2007). Because of its international economic value, this species is one of the most targeted tree for lumber in the Amazon estuary. It is used for plywood manufacturing, packaging, and for the production of sports articles, toys, pencils, sticks, reels and spools, among other products (Leite *et al.*, 2006). However, the long-term effects of the logging on the population structure of *Virola* are not well known.

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structure of *Virola* are not well known. Logging in tropical forests has two main effects on the population of trees: the spatial isolation of the remaining populations and the reduction of the total number of reproducing individuals (Sebbenn *et al.*, 2008). Pollination and seed dispersal are affected and may change the fruiting cycles and the genetic constitution of the populations (Rossetto *et al.*, 2004), especially if these plants are dioecious (Silva *et al.*, 2008). Dioecious species have individuals with unisexual flowers, which make the presence of male and female individuals in the same location essential to the success of pollination and fruiting (Bawa, 1980; Bawa *et al.*, 1985; Ackerly *et al.*, 1990). Dioecious species establish an effective synchrony and timing of flowering of the male and the female plants (Bullock, 1985). Currently, most of the várzea floodplain forests have low stocks of *Virola* (Salomão *et al.*, 2007; Jardim and Mota, 2007; Fortini and Zarin, 2011; Scabin *et al.*, 2011). Forest production is especially concentrated in the Amazon estuary region where there are large poles of logging activity (Piña-Rodrigues and Mota, 2000; Salomão *et al.*, 2007). Thus, in 1996, the Federal Government suspended logging permits of *Virola* and mahogany (*Swietenia macrophylla*), another high-value commercial timber species of the Amazon region, for a period of two years (Brasil, 1996). *Virola* is a priority species in the conservation program of genetic resources with high economic value for Brazil (Limas *et al.*, 2007;

Scabin *et al.*, 2011) and it is included in the lists of species of the Brazilian flora which are threatened by extinction at the federal level (IBAMA, 2008) and State level (SEMA, 2007). However, the logging activities in the várzea forests of the Amazon estuary do not yet consider the selection of male or female individuals of dioecious species, the diameter of the tree being the only criterion taken into account. So far, no studies exist on the impact of the removal of matriarch trees on the recruitment dynamics of dioecious species such as *Virola* in the várzeas of the Amazon estuary. Therefore, our study objective was to compare changes of the population structure of *Virola* in populations subjected to different histories of logging taking into account the gender of the trees. In similar floodplain environments, we established forest plots with different logging histories to analyze the differences of the population and diameter structure and the regeneration of this valuable tree species.

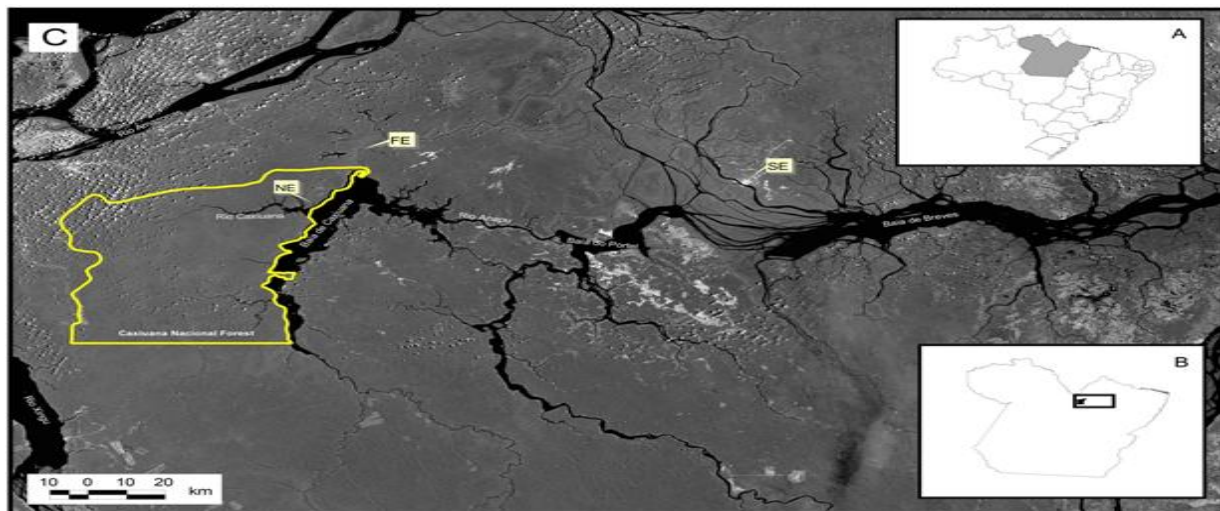
## Material and Methods

**Study area.** The present study was conducted in three sites in the floodplain forests of the Amazon estuary, in the State of Pará, Brazil (Fig. 1). These sites are representative of many forests in the region and have similar climate, soils, topography and flooding regime. The first site (unlogged = UL) lies in the Caxiuanã National Forest (1° 11 ' 44 " S and 51° 27 ' 18" W) and was never subjected to

timber logging. The second site is in IgarapéCamuim, in the vicinity of the Caxiuanã National Forest (1° 37 ' 44 " S and 51° 18 ' 54" W), where timber exploitation occurred >30 years ago but has been ceased (historically logged = HL). The third site lies in the Furo de Breves floodplain forest (1° 09 ' 48 " S and 50° 42 ' 57" W) where logging is ongoing (currently logged = CL).

**Data collection** The floristic composition and the structure of the plant populations were analyzed in 15 plots of 10 x 50 m in each site, with a minimum distance of 500 meters between each plot, placed randomly in the forest. Within each plot, all individuals of *Virola* with diameter at breast height (DBH)  $\geq 1$  cm were counted and measured. Additionally, in the UL plots of Caxiuanã National Forest, the size of trees bearing fruits was recorded. We used data from three plots of one hectare each (100 x 100 meters) which belong to the long-term research project of Caxiuanã (Projeto de Pesquisas de Longa Duração de Caxiuanã: PELD-Caxiuanã) established in lowland várzea forest. The distance between plots was about 2 km. In each hectare, all individuals with diameter at breast height (DBH)  $\geq 10$  cm were tagged and identified as specifically as possible. Individuals of *Virola* were visited in the period of peak fruiting and the presence of fruit was recorded with the aid of binoculars.

**Data analysis.** Differences of species richness and density of individuals of *Virola* and of the plant



**Fig. 1** – Location of Pará state in relation to Brazil (A), state of Pará showing the location of the Caxiuanã National Forests (B) and the three sites to subject to impact of logging, unlogged (UL), historically logged stopped 30 years ago (HL) and currently logged (CL)

community with  $DBH \geq 10$  cm (dependent variables) between the three sampling locations (independent variable) were tested with a simple Analysis of Variance. The differences between locations were compared with Tukey test, where density of individuals was log-transformed (Zar, 2010). We used an ordination analysis (McCune and Mefford, 1995) to determine differential distribution of species with  $DBH \geq 10$  cm among the plots in the three locations sampled in relation to species similarity. The relation between the presence of individuals of *Virola* bearing fruits (dependent variable) and tree diameter (independent variable) was tested with a logistic regression (Zar, 2010).

### Results and Discussion

Our study indicates that different intensities of logging result in differences of the population structure of *Virola*, particularly in the presence of regenerating matriarch trees and of juvenile trees. The three sites subjected to different intensities of logging (UL, HL, CL) clearly differed in terms of population structure and the potential for regeneration of *Virola*. However, we are aware that we have an un-replicated design with sampling restricted to three study sites. We recognize our limitations prior to the study, and we restrict our conclusions only to these three sites, each differing in logging history. Our conclusions must be corroborated by more extensive studies. Our results showed that the density of individuals of *Virola* was significantly greater in the protected UL sites ( $X = 2.71$ ;  $SD = 0.63$ ), compared to the historically logged sites HL ( $X = 1.94$ ;  $SD = 0.40$ ) and the still exploited sites CL ( $X = 1.46$ ;  $SD = 0.87$ ), which were not significantly different from each other ( $F_{[2,42]} = 23.59$ ;  $p = 0.0001$ ) (Fig. 2).

In unlogged areas, the frequency of individuals in relation to DBH showed an inverted J-shaped curve (Fig. 3A), with a high number of individuals in the small diameter classes (regeneration) and fewer individuals with large diameters. In logged areas (FE and SE), the curves did not attain this typical shape and showed very low numbers of individuals with small diameter (Fig. 3B and 3C, respectively). In CL the individuals with  $DBH > 41$  cm were almost absent. There was a reduction in the frequency of individuals in the highest diameter

class as compared to the natural stand UL by 67% (HL) and 95% (CL). Regarding the regeneration, in UL 116 individuals were found in the lowest DBH class of 1-10 cm. In HL there were 18 and in CL 20 individuals (Fig. 3), indicating 84% and 82% reduction in the frequency of individuals in this diameter class as compared to the natural stand UL. Regarding the total plant community, differences of species richness were not significant between the three sites ( $F_{[2,45]} = 1,222$ ;  $p = 0.311$ , Fig. 4B), but there were significant differences of the density of individuals of all species in the three sampled locations ( $F_{[2,45]} = 7,398$ ;  $p = 0.002$ , Fig. 4A). Species composition was clearly different between the plots with different logging histories (Fig. 5). The first axis of ordination separated the currently logged site of the historically and unlogged sites that area separated by second axes of ordination.

The greater number of individuals in the non-exploited site (UL) as compared to HL and CL was expected. The inverted J-shaped curve of the population structure of *Virola* with many individuals in the small diameter classes and a decrease with increasing diameters is typical for undisturbed forests (Nebel and Meilby, 2005; Sousa *et al.*, 2005; Sebben *et al.*, 2008; Scabin *et al.*, 2011) and indicates a balance between regeneration and mortality of individuals. Thus, the conservation area of sustainable use in the Caxiuanã National Forest, where the use of natural resources is permissible, but not logging, had a positive effect on the population structure of this otherwise heavily exploited species. The establishment of protected areas (and indigenous lands) in the Amazon has had a positive impact on the conservation of species, as deforestation inside the conservation area is lower than outside (Ferreira *et al.*, 2005). Even unprotected public and private areas in good condition for conservation may enhance the protection of natural stocks of exploited species such as *Virola*. For example, a forest inventory in an unlogged lowland forest of the timber exporter "Exportadora de Madeiras do Pará Ltda." (EMAPA), in Rio Santana, Município de Afuá, Pará, showed that *Virola* was the species with the highest value of importance and also with the highest density of individuals in natural regeneration (Gama *et al.* 2005). In addition to protected areas, efforts should be made to identify additional areas in good conservation condition.



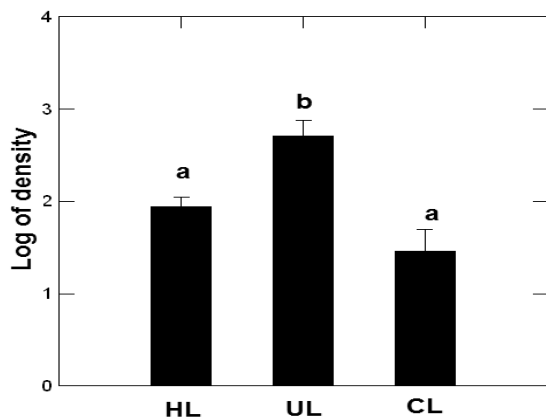


Fig. 2 – Log of density of individuals of *V. surinamensis* (Rol.) Warb (Myristicaceae) com DAP ≥ 1 cm between three sites to subject to impact of logging, unlogged (UL), historically logged stopped 30 years ago (HL) and currently logged (CL).

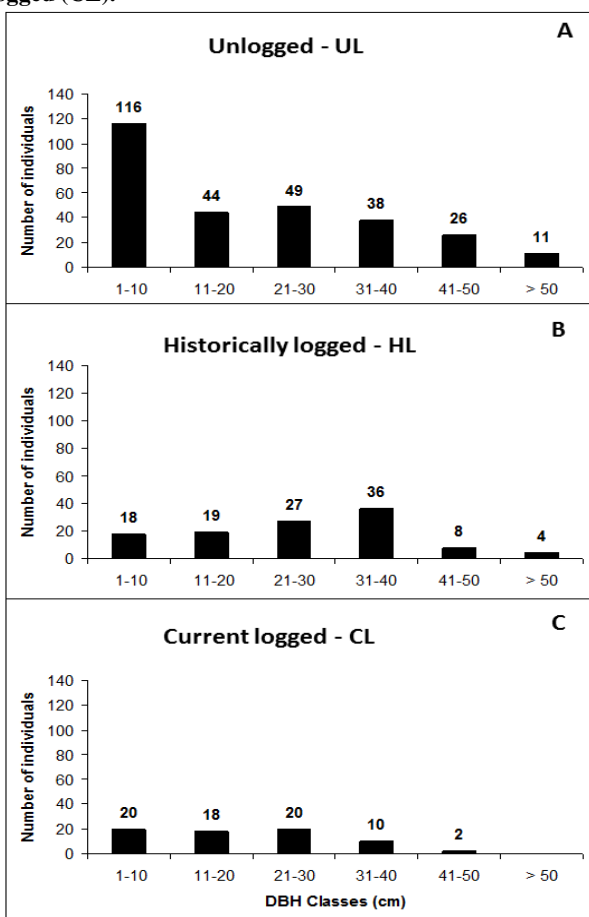


Fig. 3 - Frequency of individuals of *V. surinamensis* (Rol.) Warb (Myristicaceae) in relation to diameter classes between three sites to subject to impact of logging, unlogged (UL), historically logged stopped 30 years ago (HL) and currently logged (CL).

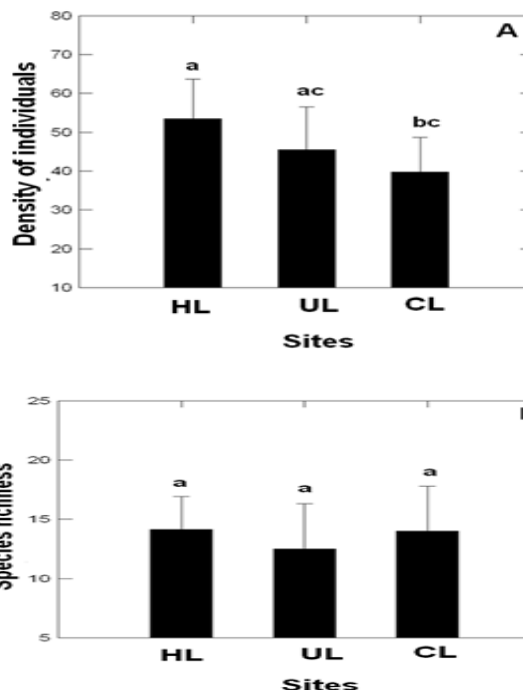


Fig. 4 - Density of individuals (A) and species richness (B) of plant community of varzea floodplain forests between three sites to subject to impact of logging, unlogged (UL), historically logged stopped 30 years ago (HL) and currently logged (CL).

In the sites with ongoing logging (CL) in our study, fewer individuals of *Virola* were to be expected (Macedo and Anderson, 1993; Fortini and Zarin, 2011). However, it was alarming that the diameter class of DBH >30 cm trees, which represents a large proportion of the reproductive individuals of this species, was almost lacking in these forests. Logging of *Virola* and of other economically valuable tree species of the lowland forests of the Amazon estuary, such as *Carapa guianensis* Aublet and *Hymenae aoblongifolia* Huber (Gama *et al.*, 2005), has occurred since for over a century and it has resulted in a drastic reduction of natural stocks of these species throughout the Amazon basin (Piña-Rodrigues and Mota, 2000; Salomão *et al.*, 2007). This is especially true for large trees, which play a critical ecological role through securing regeneration, providing abundant fruit, foliage and flowers for plant-animal-interactions (Forget and Jansen, 2007), offering niche habitats for wildlife and storing large amounts of carbon (Lindenmayer *et al.*, 2012).



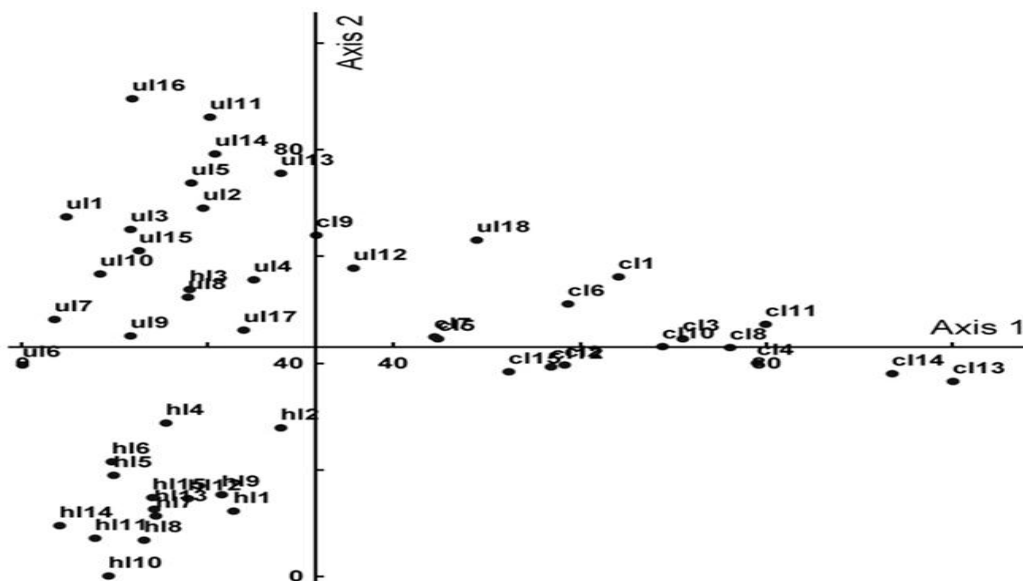


Fig. 5 - Species composition of tree plant community with DBH >10 cm of varzea floodplain forest plant community showing the clear division in relation three sites to subject to impact of logging, unlogged (ul), historically logged stopped 30 years ago (hl) and currently logged (cl).

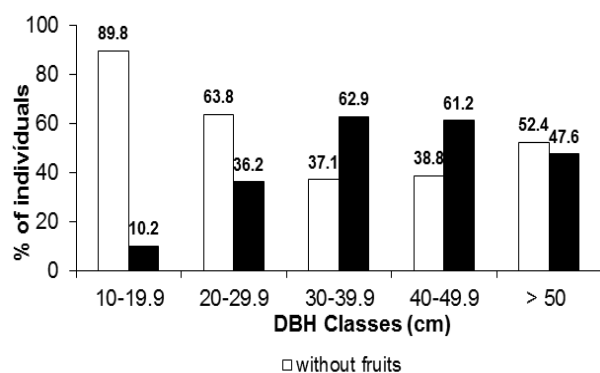


Fig.6 – Proportion of individuals of *V. surinamensis* (Rol.) Warb (Myristicaceae) with and without fruits in relation to diameter classes in a varzea floodplain forest not submitted to timber exploitation.

Interestingly, we did not find differences of species richness in the community of adult plants between the three sampling locations, but floristic composition and density of trees were significantly different between sites, showing the high disturbance caused by logging. The most surprising and alarming results however were found in the formerly exploited sites (HL). The low density of individuals of *Virola* >30 years after logging and

particularly, the lack of regeneration (small diameter class, Fig.3B), indicate that even after a long period of cessation of logging, the populations of these large trees did not recover. The drastic changes of the population of *Virola* due to logging were not restored by natural recruitment and regeneration after three decades. The density of individuals and the population structure were rather similar to the site with current logging and significantly different from the unlogged plots.

A possible explanation for this pattern is a low rate of natural regeneration caused by the lack of large reproductive trees and consequently the lack of seeds. The reduction in regeneration of *Virola* as indicated by the low number of individuals in the small diameter class (1-10 cm DBH), is perhaps the result of the elimination of reproducing female individuals, the matriarch trees which produce fruits and seeds. More data are needed to state this clearly. The individuals producing fruits are found in the diameter classes of >30 cm, which are exactly those of greatest commercial value. The most targeted individuals for logging are also those responsible for the reproduction and survival of the population. Since, in *Virola*, the reproductive

females are among the largest individuals of the population, logging has a particularly strong impact on the population structure of this species. In undisturbed environments, dioecious species exhibit a sex ratio of 1: 1 (Opler and Bawa, 1978). In our study, a change of the sex ratio as found in HL and CL. Selective logging of the large reproducing female matriarch trees can be responsible for the population declines through a reduced breeding potential. More data are needed to understand the causes and effects here. Our data point in the direction that the disequilibrium of the natural diameter classes, being interrupted or truncated at either end, results in the non-completion of the life cycle of the trees, and the whole population cannot be considered to be in balance (Kurtz and Araújo, 2000). The presence of fruits was significantly inversely related to tree diameter in *Virola* in the non-exploited plots (N = 461;  $t = -7,618$ ;  $p = 0.0001$ ), ranging from 10.2% in the smallest diameter class (10-20 cm) to 47.6% in the largest diameter class (>50 cm) (Fig. 6). The absence of pollinating and dispersing agents, such as overhunted mammals, may play a major role here, too (Redford, 1992; Peres and Roosmalen, 2002; Forget and Jansen, 2007). This is worrisome because land occupation and the use of natural resources of the lowland forests of the Amazon estuary occur almost without any management strategy, and logging is one of the main economic activities in this region (Jardim and Mota, 2007). It is alarming that a population collapse does not require a reduction of the whole population density. Changes in the sex ratio, aided perhaps by the lack of agents of pollination and dispersal, are often enough to significantly affect the reproduction of these species. Future studies should focus on the question if the elimination of the reproductive matriarchs causes changes in the reproductive potential of the residual population and, consequently, reductions in the production and recruitment of new individuals of *Virola*, as our present analyses indicate even after 30 years of recovery. The decline of adult matriarch trees is not a surprise. Populations of large old trees are rapidly declining in many parts of the world, with serious implications for ecosystem integrity and biodiversity (Lindenmayer *et al.*, 2012). Even without direct human interference, fragmented Brazilian rainforests typically see a 50 percent die-

off of big trees within 30 years of isolation. Large old trees are in decline in many ecosystems around the world as they are particularly targeted by loggers, but they are also exceptionally vulnerable to ecosystem change, including drought, increased incidence of wildfires, edge effects, and disease. These conditions can lead to elevated rates of mortality and reduced recruitment, with trickle-down effects for wildlife and plant communities (Lindenmayer *et al.*, 2012). Forest policy 40/2010 of SEMA/PA set the minimum limit of selective cutting of timber species in lowland forests at a DBH of 50 cm. Specifically for várzea and management of timber resources in the Brazilian Amazon new concepts are based on specific growth rates (Schöngart, 2008), leading to its inclusion in the timber logging legislation of the Brazilian State of Amazonas. The results of our study give way to the assumption that the currently employed cutting cycles are suitable for *Virola*. However, we suggest that the plans of forest management must consider male and female individuals of that species, as this will ensure the survival of reproductive matrices, fundamental to the repopulation of floodplain forests. One solution may be the marking of female individuals of *Virola*. Ferreira and Parolin (2007) showed that there is synchronization between flowering and flooding periodicity of the rivers in the Central Amazon, being the fruiting period associated with the high water period of the rivers, and seeds are also dispersed by water (Parolin *et al.*, 2013). Management plans should include studies on phenology and dispersal of the species of economic value also in the lowland forests of the Amazon estuary. We therefore suggest that new regulations are needed to maintain male and female individuals of *Virola* with diameters >40 cm, to ensure the persistence of the reproductive matriarch which is of fundamental importance for the conservation of this species. The most severe problem inhibiting the recovery of logged *Virola* floodplain forests of the Amazon estuary is the reduction of matriarch trees which is not sufficient to allow the natural recruitment of *Virola* and maintain the restocking process. Hand planting of seeds of *Virola* might speed up the recruitment process in previously logged site. In addition, plantations of *Virola* should be expanded. However, the criteria for selection of trees must be revised to increase the productivity of the individuals and thus



reduce the impact of forestry (Maeda *et al.*, 2001). The paradigm of sustainable logging in tropical regions assumes that these forests can be exploited repeatedly in a predetermined rotation (Barreto *et al.*, 1998). The basic assumption is that 30 years are enough for this type of forest to recover from heavy exploitation. Deggen *et al.* (2008) used a simulation model to show that selectively logging species with a rotation of 30 years caused a negative effect on the population size in three out of four timber species. Our present study shows the same for *Virola*. Given the population structures in our plots, we conclude that cutting cycles of 30 years are too short to protect *Virola*. The impact of logging undermines the ability of this species to reproduce and maintain itself in the Amazon estuary.

### Conclusion

We recommend additional studies on the natural stocks and regeneration potential of economically valuable tree species in Amazonian floodplain forests in protected areas to protect the natural populations and determine sustainable harvests. Particular attention must be paid to dioecious species which deserve special considerations in management practices. Our study

species is not unusual in its breeding system. Tropical forests have a relatively large proportion of dioecious and functionally dioecious tree species. For these trees it is particularly important to maintain large female trees for the goal of sustainable harvests. Therefore our recommendations are not limited to *Virola surinamensis* alone.

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