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Experimental harvesting of the non-timber forest product *Ischnosiphon polyphyllus* in central Amazonia

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Abstract

The harvesting of non-timber forest products has been proposed as an alternative to timber harvesting that can increase rural income while having a reduced impact on forest structure. However, surprisingly little is known about the biological consequences of harvesting these products. We conducted a 3-year experiment in which we simulated the stem harvesting of the Amazonian plant *Ischnosiphon polyphyllus*, which is used by traditional and indigenous populations in the Amazon for the construction of baskets, mats, and other handicrafts used in manioc cultivation. We found that plant mortality is limited in all except the most extreme harvesting treatments. However, we also found that plants recuperate extremely slowly from experimental harvesting. These results suggest that current harvesting strategies may not be conservative enough to ensure long-term population survival.
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1. Introduction

The harvesting of non-timber forest products (NTFPs) has emerged in recent decades as an alternative to timber harvesting that can increase rural income while having a reduced impact on forest structure (Anderson, 1990; Nepstad and Schwartzman, 1992; Peters, 1992). While several studies have

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documented the social and economic benefits of NTFPs, little is known about the biological consequences of harvesting these products (Hall and Bawa, 1993; Mendelsohn, 1994; Pedersen, 1994; Hegde et al., 1996; Murali et al., 1996; Shankar et al., 1996; Macía and Balslev, 2000). Experiments evaluating the impact of different harvesting intensities on NTFPs are extremely rare (but see Olmsted and Alvarez-Buylla, 1995; Nantel et al., 1996). For NTFPs that come from plants, the level of harvest that will ensure long-term plant growth and survivorship is for the most part unknown. These data on individual responses to harvesting are critical, because they are an essential component of demographic models

used to project population dynamics under alternative management strategies (Olmsted and Alvarez-Buylla, 1995; Nantel et al., 1996). The paucity of information is particularly acute in tropical regions, where NTFPs are promoted as an alternative to commercial timber extraction in many countries (Nepstad and Schwartzman, 1992; Hegde et al., 1996; Arnold and Perez, 2001). In the absence of information about plant responses to harvesting, management plans for NTFPs are often developed and implemented on the basis of limited ecological data.

Arumã is the common name given in Amazonia to several species of large, erect, perennial herbs in the genus *Ischnosiphon* (Marantaceae). The mature stems of Arumã, which can reach lengths of 1.3–4.0 m, are cut and used to make baskets and sifters for manioc cultivation by various Amazonian indigenous groups including the Baniwa and Waimiri-Atroari (Milliken et al., 1992; FOIRN/ISA, 2000). When sold as handicrafts, these objects have become indispensable to the subsistence economy of many of these indigenous groups, as well of traditional riverine communities (Shepard et al., 2001; Nakazono, 2000). For instance, a recent study conducted in Brazil found that the production of Arumã items could total as much as 56% of the official annual minimum wage, even if families only crafted items for a portion of the year (Nakazono, 2000).

Ischnosiphon polyphyllus is a widely distributed species of Arumã found around the uppermost Rio Orinoco, in the Rio Negro basin, and along the Rio Amazonas from Tefé to its mouth (Anderson, 1977). Although some Arumã species are found on *terra-firme* forests, *I. polyphyllus* occurs almost exclusively in swampy habitats and areas subject to annual flooding cycles, such as the banks of streams and on seasonally inundated islands. In the central Amazon, *I. polyphyllus* is commonly found in the archipelago of islands making up the Anavilhanas Ecological Station (AES), a large protected area 150 km northwest of Manaus, Brazil (Fig. 1). These islands were traditionally the primary source of Arumã for members of the Artisans Association of Novo Airão (AANA), a community group whose members collect plants to produce handicrafts they sell both locally and internationally (Projeto Fibrarte, 2000).

Collection in the AES had historically proceeded without restrictions. In 2000, however, the Brazilian Ministry of Environment and Renewable Resources (IBAMA) began to enforce statutes prohibiting its collection without an approved management plan. In response, the AANA, in collaboration with a local non-governmental organization (Fundação Vitória Amazônica), developed a plan to collect in the nearby municipality of Novo Airão. This plan, which is still being negotiated, stipulates that no more than 50% of a plant's mature stems should be harvested for handicraft production. Observations conducted while accompanying collectors indicated they harvested 20–80% of mature stems (mean $= 53.1\% \pm 22.7$ S.D.; Nakazono, 2000).

Here we report on the results of a 3-year experiment conducted in the AES, in which we simulate the harvesting of *I. polyphyllus* stems by local collectors. Specifically, we ask the following two questions: First, does increasing intensity of stem collection increase
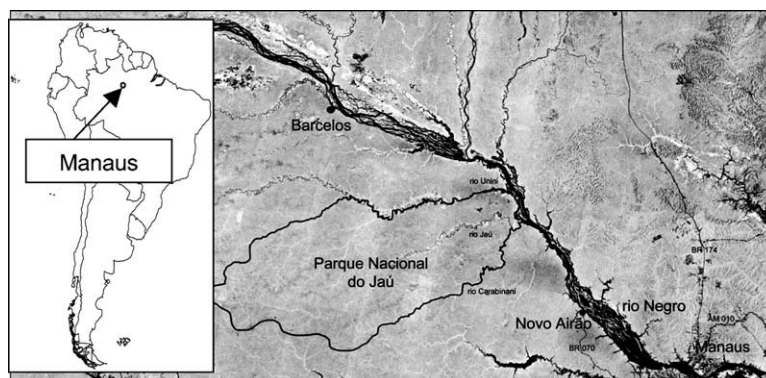

Fig. 1. Map indicating the location of Manaus, Novo Airão, and Jaú National Park, Brazil.

the risk of plant mortality? Second, are there levels of experimental harvesting that allow for plants to recover stem growth within 3 years? Our goal in conducting this experiment was to both evaluate the proposed 50% harvesting limit and determine the impacts of alternative harvesting strategies.

2. Methods

The experiments were conducted on eight islands in the AES, all of which were approximately 30 km from the town of Novo Airão ($60°57'6''$W, $2°37'10''$S). With the help of local collectors, we chose 120 *I. polyphyllus* on these islands that met the criteria required for handicraft production (mean $= 7.04 \pm 0.643$ S.E. plants/island, range $= 8-30$). After marking all plants with a numbered aluminum tag, we counted the total number of stems on each plant and assigned each stem to one of five categories defined by the collectors (Table 1). Experimental plants were composed almost entirely of stems in the fifth category ("mature stems"; $88.6\% \pm 1.1$ S.E.), which are the ones most frequently collected by harvesters (Nakazono, 2000).

We randomly assigned selected plants to one of five simulated harvesting treatments: 0, 30, 50, 80, or 100% of the mature stems removed ($n = 24$ plants per treatment). Stems were removed 15 cm above the soil surface with a machete, replicating the common harvesting practice. We marked plants, measured them, and harvested stems in October 1998. We then returned to count and categorize all stems on plants in October 1999, November 2000, and November 2001.

Since plant growth, and therefore post-harvest recovery, is often dependent on the amount of sunlight, we also estimated light levels to which plants were exposed in 1998 and 2001 using the method of Clark and Clark (1992). Estimates made using this method categorize the light environment on an ordinal scale ranging from 1 (no direct light, closed canopy) to 5 (vertical light penetration, completely open canopy). While subjective, these broad categories are well-correlated with estimates of canopy openness calculated with hemispheric photographs (Clark and Clark, 1992).

Plants in the different harvesting treatments had similar number of mature stems at the start of the experiment (mean of all plants combined $= 10.27 \pm 0.64$ S.E., median $= 8$; Kruskal–Wallis test, $H = 1.08$, $P = 0.90$), as well as similar proportions of mature stems (mean of all plants combined $= 88.6\% \pm 1.1$ S.E., median $= 8$; Kruskal–Wallis test, $H = 3.11$, $P = 0.54$). In addition the light levels to which plants in the different treatments were exposed were not significantly different at the start of the experiment (Kruskal–Wallis test, $H = 0.300$, $P = 0.99$).

We first compared the survivorship of the 120 plants in the different harvesting treatments using *G*-tests. To meet the assumptions of contingency table analysis (see Zar, 1999), it was necessary to pool plants from the control treatment with those from the 30% harvesting treatment. We pooled plants from 50 to 80% harvesting treatments for the same reason.

To test for differences in post-harvest growth of plants in the different harvesting treatments, we used repeated measures analysis of covariance. The dependent variables were the proportional change in stem number (Δ_{stem}) after 1, 2 and 3 years, calculated as:

proportional change in stem no.

$$(\Delta_{\text{stem}}) = \frac{\text{Stem}_{2001} - \text{Stem}_{1998}}{\text{Stem}_{1998}}$$

Prior to analysis, Δ_{stem} was square-root-transformed to meet the assumptions of parametric statistics. Harvest-

Table 1
Categories to which stems on experimental plants *I. polyphyllus* were assigned

Stem category	Basal diameter (cm)	Stem length (m)	Branched tip	Number of leaves
New	≤ 1.5	≤ 1	No	0
Immature	≥ 1.5	>1	No	≤ 4
Fine	≤ 1.5	≤ 1	Yes	>4
Mature-slender	≤ 1.5	>1	Yes	>4
Mature	>1.5	>1	Yes	>4

ing treatment (0, 30, 50, 80, 100% of mature stems removed) was the independent variable, with the plant's original number of mature stems and the mean of 1998 and 2001 light estimates as covariates. Student–Newman–Keuls post-hoc tests were used to compare the means of significant main effects. Note that while the analysis was conducted on proportional changes in plant size, we converted these values to percentages and present converted values throughout the paper. Results were similar for comparisons of growth rates using alternative measurements of plant size (e.g., total basal diameter, plant height). We therefore present only the results based on changes in stem number.

3. Results

All plants in the control treatment (0% harvested) survived to the end of the experiment, and only 1, 1, and 3 plants died in the 30, 50, and 80% harvesting treatments, respectively. However, over half (13/24) of the plants in the 100% harvesting treatment died over the course of this study. The difference in survivorship between pooled treatment categories was highly significant ($G^2 = 31.09$, $P < 0.0001$).

The light levels to which plants were exposed in 2001 were significantly lower than they were in 1998 (mean light level$_{1998}$ = 3.18 ± 0.11 S.E., mean light level$_{2001}$ = 2.66 ± 0.094 S.E.; Wilcoxon signed rank test, $Z = -4.479$, $P < 0.0001$), though light levels were similar for the different harvesting treatments (Kruskal–Wallis test, $H = 7.876$, $P = 0.10$).

The proportional change in plant size was significantly different among harvesting treatments (MS = 0.337, $F_{4,94} = 3.21$, $P = 0.02$, Table 2). Plants never recovered completely from any harvesting treatment, and 3 years after the removal of stems they were only 36.5–61.5% of their original size (Fig. 2). However, control plants from which no stems were collected were also smaller than when the experiment began (74.7% ± 5.4 S.E. of their original size). There was substantial inter-annual variability in growth rates, as indicated by the significant effect of measurement interval (MS = 0.113, $F_{2,188} = 6.911$, $P < 0.0001$). There was also a significant main effect of the light environment in which a plant was found ($P < 0.0001$, Table 2), with plants in high-light environments loos-

Table 2
Repeated measures analysis of covariance testing for effects of simulated harvesting on *I. polyphyllus* growth[a]

Effect	DF	MS	F	P
Harvesting level	4	0.337	3.21	**0.02**
Initial no. of mature stems	1	0.223	2.13	0.15
Average light level	1	1.697	16.17	**<0.0001**
Harvest × stems	4	0.181	1.72	0.15
Harvest × light	4	0.208	1.98	0.10
Stems × light	1	0.408	3.89	**0.05**
Harvest × stems × light	4	0.181	1.73	0.15
Subject (group)	94	0.105		
Time	2	0.113	6.91	0.001
Time × harvest	8	0.016	1.00	0.44
Time × stems	2	0.016	1.00	0.37
Time × light	2	0.057	3.48	**0.03**
Time × harvest × stems	8	0.012	0.71	0.68
Time × harvest × light	8	0.019	1.41	0.34
Time × stems × light	2	0.018	1.12	0.33
Time × harvest × stems × light	8	0.014	0.82	0.58
Time × subject (group)	188	0.016		

[a] Significant results are in bold.

ing fewer stems than those in low light environments (Fig. 3). Finally, there was a significant interaction between time since harvest and the average light level to which plants were exposed ($P = 0.033$), as well as a marginally significant interaction between the original number of stems a plant had and average light levels ($P = 0.052$, Table 2).
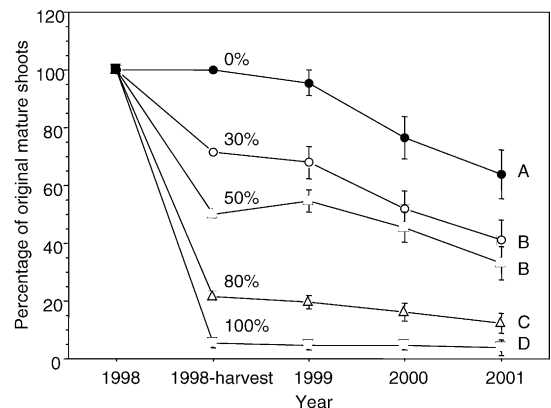

Fig. 2. The mean growth of Arumã plants in each of five experimental harvesting treatments. Treatments with significantly different growth rates are indicated with different letters.
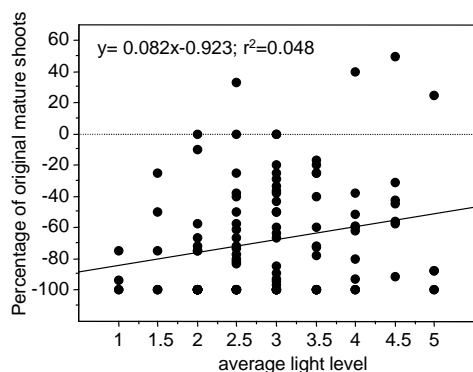
Fig. 3. Regression of the post-harvest growth of Arumã individuals vs. the average light levels to which they were exposed over the course of the experiment.

4. Discussion

To our knowledge, this study is the first to experimentally assess the consequences of harvesting tropical herbaceous plants used in the production of NTFPs. While our results demonstrate that plant mortality is limited in all except the most extreme harvesting treatments, we also show that plants recuperate extremely slowly from experimental harvesting.

4.1. Patterns of Arumã growth and mortality in different harvesting treatments

Adult mortality was very low in the 0–80% harvesting treatments, with only 4 of 96 experimental plants dying during the 3 years following experimental harvesting. In contrast, over half the plants from which 100% of the stems were experimentally removed died. Removing all mature stems, even when immature and new stems are left behind, is clearly not a sustainable harvesting strategy.

While growth following harvesting was significantly different among treatments, the results were contrary to what we expected. Plants from which 30–80% of the mature stems were harvested were on average 59–67% smaller than when the experiment began. However, control plants from which no stems were harvested lost 36% of their stems over the course of the study. The observed changes in plant size were not consistent across each time interval, as indicated by the significant effect of "Time" in the analysis of variance.

Why are Arumã individuals shrinking, even those from which no stems were harvested? The precise mechanisms responsible for the growth responses we observed remain unclear. They may, however, be a function of the size of plants selected for the experiment. We focused only on larger plants favored by collectors, which may have lower growth rates because they are senescing or because they are physiologically constrained from growing larger. Limited variation in initial plant size may also be the reason why the effect of plant size was not significant in our ANOVA. In addition, while herbivores or pathogens could both reduce plant growth rates, we have no evidence to suggest this is the case (Nakazono, pers. observation). Instead, the significant effect of light levels on plant growth and results from prior studies suggest reduced growth can be at least partly due to the reduced light levels associated with gap succession and canopy closure.

Gap dynamics have been shown to influence seedling recruitment (Smith, 1987; Horvitz and Schemske, 1994), survival (Mulkey, 1986; Mulkey et al., 1991) and reproduction (Dirzo et al., 1992) of a number of understory herb species. They can also have a major impact on plant growth rates (Mulkey, 1986; Pfitsch and Smith, 1988; Mulkey et al., 1991), which are high during the early stages of gap formation and stable or negative as gap succession and closure proceeds. Most of the plants used in our study were in high-light environments when the experiment began, and the amount of light to which each plant was exposed was significantly lower by the end of the experiment. The negative plant growth rates we observed during our experiments probably reflect, at least in part, reductions in photosynthetically active radiation resulting from lower light availability in these locations.

Two recent studies further support the conclusion that a dynamic light environment can influence the growth and population dynamics of Arumã. In non-flooded central Amazonian forests, the closely related species *I. arouma* exhibited positive growth rates in areas that were selectively logged, which was almost certainly due to the higher light intensity (Costa et al., 2002). Similarly, the regeneration of Arumã species from the upper Rio Negro Basin also is closely linked to forest disturbance, in this case the clearing opened for agriculture by the Baniwa Indians (Shepard et al., 2001).

4.2. Implications for the management of I. polyphyllus and future directions

Our results have several implications for the management of *I. polyphyllus* and other Arumã species. First, the substantial loss of stems by control plants indicates some stems can be collected from plants, particularly those that have reached their maximum size. Given that there was no significant difference between the 30 and 50% harvesting treatments, we suggest the current 50% harvesting limit appears to be appropriate. However, we also note that a more conservative harvesting limit would serve as a buffer against occasional overharvesting. Furthermore, additional work is needed to determine what harvesting levels are sustainable in other habitats, such as the black-water streams (i.e., "*igarapés*") where Arumã is also harvested by AANA members.

Second, our results also indicate that plant recovery is positively linked to the light environment to which plants are exposed (Fig. 3). While additional experiments that explicitly compare growth in shaded understories and gaps are needed, we suggest gaps and other high-light environments are probably the most appropriate places to harvest Arumã and other understory herbs used in NTFP production. Future empirical work could also explore thinning the canopy around adult plants to promote growth (Mesquita, 2000) and transplanting individuals to high-light environments, both of which are standard practices in forest management.

Finally, our results underscore the necessity of long-term studies for developing appropriate management plans for NTFPs. Had our experiment ended after only 1 year, we would have erroneously concluded that the 50% harvesting limit was an appropriate management strategy for *I. polyphyllus*, since plants in that treatment exhibited a slight increase in post-harvesting size. Instead, our study suggests that this rule may not be conservative enough to insure the long-term survival of individuals from which stems are harvested. While, to our knowledge, no studies have experimentally simulated harvesting in the field to study the impacts of collecting NTFPs, the few studies that have done so using modeling or other non-experimental methods are typically conducted on temporal scales of months rather than years (but see Nantel et al., 1996; Ticktin and Johns, 2002). While longer studies are often costly to conduct and require an intense sampling effort, our results suggest decisions made on the basis of short-term data could lead to inaccurate conclusions regarding the ultimate success of alternative NTFP harvesting strategies.

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