EFFECTS OF HARVESTING ON THE STRUCTURE OF A NEOTROPICAL WOODY BAMBOO (*Otatea:* GUADUINAE) POPULATIONS

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SUMMARY

Natural populations of Otatea acuminata *(Munro) C.E. Calderón & Soderstr. subsp.* aztecorum *(McClure & E.W. Smith) R. Guzmán, Anaya & Santana-Michel were studied in the Sierra de Manantlán, Jalisco-Colima, in Western Mexico. The objectives were to compare the structure of otate populations at different harvesting levels, in order to evaluate the changes occurred due to management and to obtain the best prediction factor for culm production. Forty-one 50m² plots were randomly established in harvested and non-harvested stands, and were observed over a 2 year period. There was no significant difference between harvested and unharvested stands, but the latter had higher densities and longer stems on average. Culm diameter and height were significantly different according to soil type in a nonparametric ANOVA. A backward lineal regression analysis identified a prediction model for juvenile culms production. Present exploitation levels by artesans appear to be sustainable.*

RESUMEN

Se estudiaron poblaciones naturales de Otatea acuminata *(Munro) C.E. Calderón & Soderstr. subsp.* aztecorum *(McClure & E.W. Smith) R. Guzmán, Anaya & Santana-Michel en la Sierra de Manantlán, Jalisco-Colima, en el occidente de México. Los objetivos fueron comparar la estructura de las poblaciones con diferentes niveles de aprovechamiento, para evaluar los cambios debidos al manejo y obtener el mejor factor de predicción en la producción de tallos. Se establecieron 41 sitios de 50m² y se observaron durante 2 años. No hubo diferencia significativa entre sitios cosechados o no, pero éstos últimos tuvieron, en promedio, mayores densidades y tallos más largos. El diámetro y altura de los tallos mostraron diferencias significativas de acuerdo con el tipo de suelo mediante un análisis de varianza no paramétrico. Un análisis de regresión lineal de retroceso identificó un modelo de predicción para la producción de tallos jóvenes. Los niveles actuales de explotación por artesanos parecen ser sostenibles.*

Introduction

About 2.5 billion people worldwide use bamboo and there are 1250 known species with more than 1500 possible uses (FAO, 2000). Bamboos are primitive grasses that grow worldwide except in Europe, and nearly half of the species around the world are native to America, including woody and herbaceous bamboos. In Mexico the genera of woody bamboos with the widest distribution are *Chusquea*, *Guadua*, *Olmeca* and *Otatea* (Judziewicz *et al.*, 1999).

One of the most common genera in Mexico is *Otatea*, a woody bamboo native to Mexico and Central America where it is called 'otate' (Guzmán *et al*., 1984). The name 'otate' means solid cane, and is derived from the nahuatl native language. This name is also used in some parts of Mexico for *Rhipidocladum racemiflorum* (Steudel) McClure, *Guadua longifolia* (E. Fourn.) R.W. Pohl, *Guadua amplexifolia* J. Presl (Santamaría, 1978) and *Chusquea* spp., as well as for some species of the genus *Arundo*, which is not a bamboo.

Otate is a semelparous plant with a 30 to 35 year life cycle, and it produces new shoots every year during the rainy season, from July to September (Vázquez-López *et al*., 2000). New, annual vegetative shoots reach their maximum size in 3-4 months, and stop growing. At this time, they cannot be harvested. The first, second and sometimes third year culm, depending on environmental conditions, are recognized by local people as "new stem" but herein referred to as "juvenile". These culms are selected for basket manufacturing because of their flexibility. Older culms (herein "mature"), usually more than 3 years old, are hard and are used as a construction material and for stakes in agriculture (Vázquez-López *et al.*,

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RESUMO

Estudaram-se populações naturais de Otatea acuminata *(Munro) C. E. Calderón & Soderstr. subsp.* aztecorum *(McClure & E. W. Smith) R. Guzmán, Anaya & Santana-Michel na Serra de Manantlán, Jalisco-Colima, no ocidente do México. Os objetivos foram comparar a estrutura das populações com diferentes níveis de aproveitamento, para avaliar as mudanças devido ao manuseio e obter o melhor fator de predição na produção de caules. Estabeleceram-se 41 lugares de 50 m² e se observaram durante 2 anos. O diâmetro e altura dos caules mostraram diferenças significativas com o tipo de solo mediante uma análise de variância no paramétrico. Uma análise de regressão linear de retrocesso identificou um modelo de predição para a produção de caules jovens.*

2000). About 7 to 8 years after emerging, the culms lose their consistency and become brittle and unhealthy. Afterwards, they die away, but new shoots replace them. When the flowering process is about to initiate, individuals stop producing new shoots and, also, every culm becomes brittle and unhealthy. After flowering all culms die away. During all the period of study, the *Otatea acuminata* stands in the area are flowering. Nevertheless, harvesting can continue because flowering is irregular in time and space. Flowering takes place in patches and some populations maintain vegetative propagation while others are in the sexual reproduction phase. The seedlings are fragile and highly sensitive to trampling and herbivory. The plants generated from seed (sexual propagation) reach their full size from 7 to 8 years after germination (Vázquez-López *et al*., 2000). Seeds may germinate in the same year they are produced.

Otatea forms dense thickets in tropical deciduous forests, called "otatales" (Santamaría, 1978). The tropical deciduous forest is noted for its high diversity, endemism and richness in useful species (Rzedowski, 1978; Benz *et al.*, 1994; Cuevas-Guzmán *et al.*, 1998). In the studied area *Otatea acuminata* subsp. *aztecorum* is one of the most abundant and useful species from this type of forest and it has been used for more than a century.

Deforestation rates in tropical deciduous forests in Mexico are high; the surface covered by this biome was reduced from 16 to 6% in 20 years (Flores *et al*., 1971; Lott *et al.*, 1987; SARH, 1992, 1994; Mooney *et al.*, 1995; Challenger, 1998; Trejo and Dirzo, 2000). Though data were obtained with different techniques and objectives, which makes it difficult to assess deforestation rates accurately, they give an idea of the extent of the loss of this vegetation type in the country. The main causes of deforestation are changes in land use, such as the introduction of grasses for extensive cattle grazing, as well as slash and burn agriculture (Miranda and Hernández, 1963; Rzedowski, 1978; Miller and Kauffman, 1998; Pennington and Sarukhán, 1998), timber extraction (Trejo and Dirzo, 2000) and repeated harvesting of useful species (Bye, 1995). This last factor, if done properly, also could be helping reduce deforestation, using it as a controlled harvest that could render enough benefits to the owners for avoiding land use changes.

The aim of this study is to compare the structure of otate populations at different harvesting levels, in order to evaluate the changes due to current harvest practices and to obtain the best prediction factor for culm production.

Methods

Study site

The study was carried out in the community of Platanarillo, in the northwestern region of the state of Colima, Western Mexico, between 19º21'16" and 19º28'52"N, and 103º55'27" and 104º01'09"W. It is located in the southeastern part of the Sierra de Manantlán, within the Sierra de Manantlán Biosphere Reserve, in a canyon with slopes ranging from 25 to 100% and altitudes from 900 to 1800m. The climate is mid-latitude tropical sub-humid, according to the modified Köppen classification system (García, 1972), with a dry season Oct to May and a rainy season Jun to Sept, an average annual precipitation of 1350mm, and an average annual temperature of 22ºC (Martínez-Rivera *et al*., 1991). Most of the soils are derived from karstic limestone (Lazcano, 1988). These are Lithosols, which are rocky, shallow, and infertile soils. Regosols overlying igneous material occupy an important part of the area; these soils are deeper with less rocks and more organic matter (INEGI-SPP, 1981). Tropical deciduous forest covers the greatest portion of the study area. Here, *otatales* are an important component of the landscape and they occupy 800ha, according to satellite images (IMECBIO, 2000), even though only 300ha are accessible for harvesting.

Data collection

Forty-one 50m² (10 x 5m) plots were randomly established between 1997 and 1999 in harvested (19) and in non-harvested (22) areas. Every site was north-south oriented on its 10m side. Slope, rockiness, aspect and altitude were registered, as well as evidences of harvesting levels (number of stumps), fire, and grazing. Rockiness, fire, and grazing were determined according to Olvera-Vargas *et al*. (1996). Every culm was located, and their height and diameter at breast height (dbh) were measured within each plot. Three use categories and two health categories were recorded. Use categories were 1) "juvenile" referred to green culms, no more than 3 years old, with spiculate culm sheaths; 2) "mature" referred to green-yellowish culms with few culm sheaths; and 3) "overmature" or "dry" referred to completely yellow to grayish culms without culm sheaths nor foliage and with brittle stems. The limit of the potential life span of one culm seems to be 8 years. Health status was defined as 1) 'healthy' for green culms with complete foliage and regular internodes, or 2) 'unhealthy' for yellowish culms with scanty foliage and irregular internodes.

Data analysis

A nonparametric ANOVA was applied in order to find differences between sites using harvesting levels, grazing intensity and soil types as grouping variables. The Kruskal-Wallis test was applied using Wilcoxon scores (rank sum). Harvest levels were determined by the percentage of culms that were extracted: 0= Null (0%), 1= Low (10%), 2= Medium (20%), 3= High (>20%), and also simply as harvested *vs* non-harvested. The test was applied to density, height and dbh for every factor. Clustered error bars were calculated for density since it was the variable with the highest variation. The best prediction factor for culm production was identified with a backward linear regression analysis, using density of juvenile culms as the dependent variable. Data were analyzed with the SPSS program V. 10.0 (SPSS, 1999).

Results

Structural characteristics

For all the sites, variation of densities was greater than that of height and dbh (Table I), and in non-harvested sites

TABLE I
STRUCTURAL VARIABLES IN HARVESTED AND NON-HARVESTED STANDS OF *Otatea acuminata* SUBSP. *aztecorum* IN THE STATE OF COLIMA, WESTERN MEXICO

Variable	Harvest condition	n	Mean ±s.d.	Variation coefficient(%)
Height (m)	harvested	722	4.59 ± 1.43	31.2
	non-harvested	767	4.47 ± 1.20	26.8
DBH (cm)	harvested	722	2.43 ± 0.63	25.9
	non-harvested	767	2.29 ± 0.60	26.2
Density (culms/ha) of juvenile culms	harvested	19	1452.63 ± 705.04	48.5
	non-harvested	22	1263.64 ± 751.85	59.5
Density (culms/ha) of mature culms	harvested	19	5052.63 ±2596.44	51.4
	non-harvested	22	4200.00 ±2111.19	50.3
Density (culms/ha) of dry culms	harvested	19	1094.74 ± 767.01	70.1
	non-harvested	22	1509.09 ±1272.01	84.3
Total culm density (culms/ha)	harvested	19	7600.00 ±3380.34	44.5
	non-harvested	22	6972.73 ±3225.08	46.3

variation was greater than that in harvested sites for juvenile and dry culms. Total density was not significantly different among harvesting levels (χ^2=0.456, df=3, P=0.928), grazing intensity (χ^2=0.776, df=2, P=0.679) or soil type (χ^2=0.975, df=1, P=0.324). Densities of culms by use categories were also not significantly different among harvesting levels (juvenile culms: χ^2=4.315, df=3, P=0.229; mature culms: χ^2=1.0, df=3, P=0.810 and dry culms: χ^2=4.436, df=3, P=0.218), grazing intensity (juvenile culms: χ^2=2.652, df=2, P=0.266; mature culms: χ^2=0.425, df=2, P=0.808 and dry culms: χ^2=1.832, df=2, P=0.4), nor soil types (juvenile culms: χ^2=0.0, df=1, P=0.988; mature culms: χ^2=1.517, df=1, P=0.218 and dry culms: χ^2=1.170, df=1, P=0.279). However, the average densities of juvenile and mature culms were consistently higher in harvested stands (Table I).

Comparison of dbh and height did not show significant differences among harvesting levels (juvenile culms dbh: χ^2=1.153, df=3, P=0.764; mature culms dbh: χ^2=4.387, df=3, P=0.223 and dry culms dbh: χ^2=2.958, df=3, P=0.398; juvenile culms height: χ^2=0.718, df=3, P=0.869; mature culms height: χ^2=4.954, df=3, P=0.175 and dry culms height: χ^2=1.771, df=3, P=0.621); or grazing intensity (juvenile culms dbh: χ^2=0.626, df=2, P=0.731; mature culms dbh: χ^2=3.187, df=2, P=0.203 and dry culms dbh: χ^2=2.479, df=2, P=0.289; juvenile culms height: χ^2=3.052, df=2, P=0.217; mature culms height: χ^2=5.829, df=2, P=0.054 and dry culms height: χ^2=2.684, df=2, P=0.261), but rendered significant differences between soil types (juvenile culms dbh: χ^2=5.980, df=1, P=0.014, mature culms dbh: χ^2=11.874, df=1, P=0.001 and dry culms dbh: χ^2=11.671, df=1, P=0.001; juvenile culms height: χ^2=3.66, df=1, P=0.056; mature culms height: χ^2=7.138, df=1, P=0.008 and dry culms height: χ^2=3.21, df=1, P=0.073). Greatest dimensions were observed in harvested sites (Table I), and the longest culms were found in regosols.

Total density appears to be the best descriptor for the effects of harvesting. We used clustered error bar graphics (confidence interval 95%) to demonstrate differences within the two-year period. There is a considerable change in densities of juvenile and dry culms. Recruitment in 1997 was higher than mortality, whereas in 1999 recruitment decreased and mortality increased (Figure 1). Figures 2 and 3 show this variation in recruitment and mortality broken down by management type. The non-harvested stands show a lower density of mature culms and a higher mortality than harvested ones.

Harvesting intensity and prediction of shoot production

Stump density indicated a reduction in harvesting level

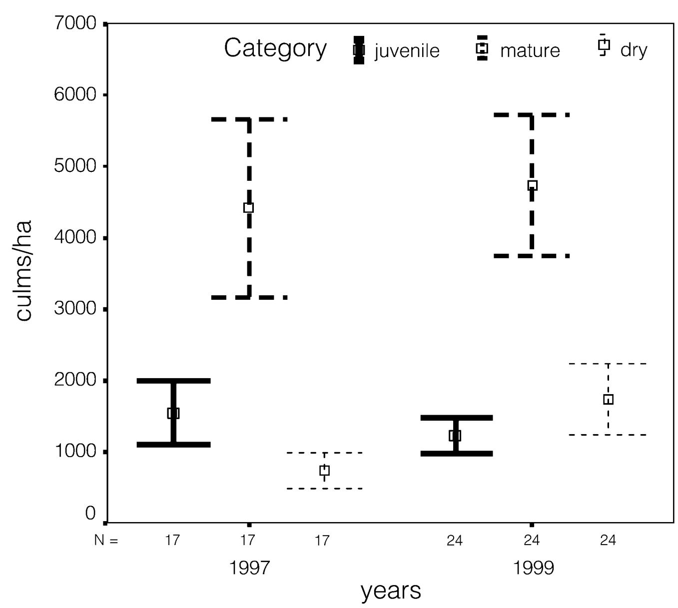

Figure 1. Density of *Otatea acuminata* subsp. *aztecorum* culms by use category and by year. N: number of plots.

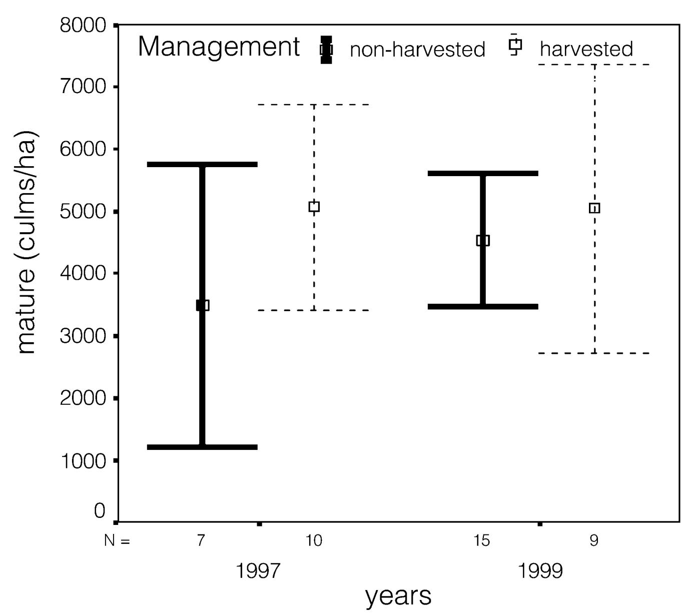

Figure 2. Mature *Otatea acuminata* subsp. *aztecorum* culm density by type of management and by year. N: number of plots.

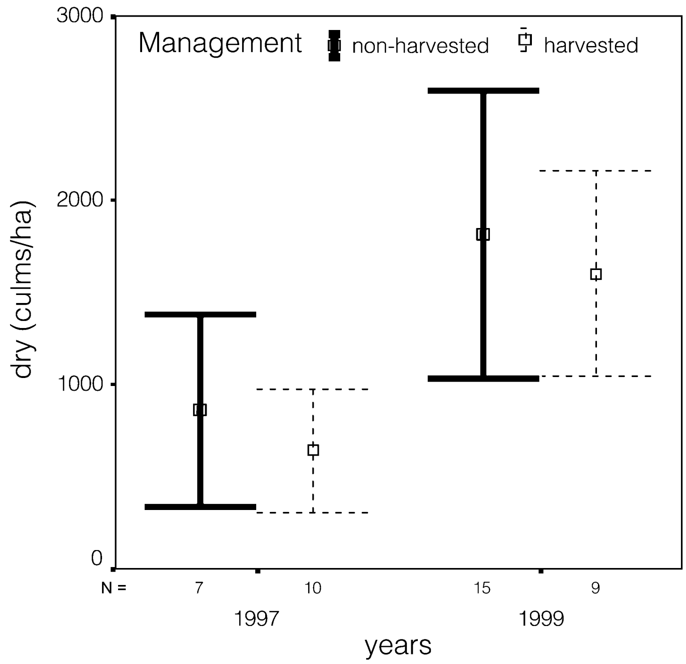

Figure 3. Dry *Otatea acuminata* subsp. *aztecorum* culm density by type of management and by year. N: number of plots.

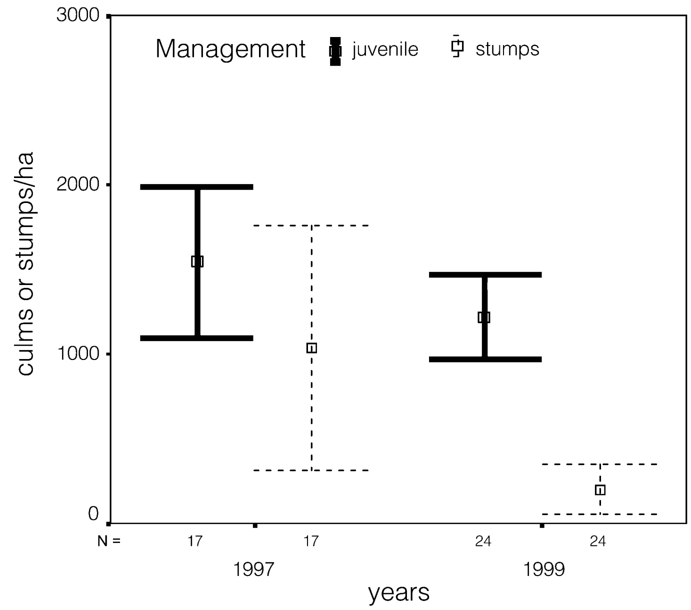

Figure 4. Density of *Otatea acuminata* subsp. *aztecorum* juvenile culms and stumps by year. N: number of plots.

(Figure 4); in 1997, 32% of the juvenile culms were harvested, whereas in 1999 only 9% were. As harvesting levels decreased in the studied *otatales*, the number of healthy culms decreased too. Dry and unhealthy culms increased from 1997 to 1999 (Table II). Linear backward regression analysis identified density of mature culms as the best predictor for shoot production (Figure 5): y= 0.1942x + 458.679, where y: density of juvenile culms and x: density of mature culms; N=41, R^2=0.396, F=25.578 (P<0.05), t=5.057 (P<0.05).

Discussion

Although not significant, data suggest that harvesting increases shoot production (Table I; Figure 4), stimulates growth of rhizomes and roots, and perhaps storage of nutrients. This could be interpreted as compensatory growth (McNaughton, 1983), which increases net primary productivity after harvesting or grazing in many plant species as a result of an increment in relative growth rates of shoots (Olson and Richards, 1988).

Significant differences were found for populations growing on different soils; deeper soils predictably had lasger otates. However, mean differences were too small (0.12m in height and 0.14cm in dbh, see Table I) to influence harvesting. Yet, culms were slightly larger in harvested sites. These sites had the highest densities of juvenile and mature culms and the lowest density of dry culms (Figure 3). Similar results were reported by Vázquez-López *et al*. (2000) using a different sampling method and data analysis.

Under a traditional management system of *otatales* in the study area there is no planned selection of areas for harvesting. The main criteria for choosing a harvesting site are accessibility and proximity to villages. In practice, there are two additional factors that restrict harvesting and affect the populations. First, recent delimitation of individual land property in communal lands due to new property rights oblige artisans to look for new harvesting zones. Second, a sequential prolonged flowering process from 1993 onwards has diminished the stock of useful otate culms. Before flowering the culms become brittle and unhealthy and have several holes, 3-4.5mm in diameter, likely caused by some Curculionidae species observed in the field that are used afterwards as nests by wasps, probably from the worldwide distributed genus *Psenulus* (Matthews, 2000). Thus, these *otatales* are no longer useful for basketry nor as stakes. However, even in stands with imminent flowering annual harvesting was lower than recruitment in both years of the study. This suggests that traditional harvesting has been done at a conservative level and does not deteriorate the resource.

This study showed that mature culm density is the best predictor for culm production. This indicates that juvenile culm production is a function of the number of mature culms nearby, though an excess of mature culm limited re-sprouting (Vázquez-López *et al., 2*000) and recruitment decreased as density increased. This effect may be due to an intraclonal regulation of the new shoot natality or even self-thinning by mortality of genets (Makita, 1996). Similar results were obtained by Taylor and Qin (1993) in China. In Colombia, most "guaduales" (*Gua dua*'s populations) without management had high proportions of mature and dry guaduas and few juvenile culms (Cruz, 1994). Similar tendencies were encountered by Christanty *et al.* (1996) in an agroforestry management system in a humid tropical region in Indonesia, as well as by Singh and Singh (1999) in an experimental bamboo plantation in a dry tropical region in India.

Otate's potential production is considerable. For example,

TABLE II
RELATIONSHIP BETWEEN HEALTH STATUS AND MANAGEMENT TYPE OF *Otatea acuminata* SUBSP. *aztecorum* CULMS IN 1997 AND 1999, IN THE STATE OF COLIMA, WESTERN MEXICO

Vitality	1997		1999	
	Non-harvested sites (%)	Harvested sites (%)	Non-harvested sites (%)	Harvested sites (%)
Alive healthy	58.1	59.5	43.6	38.3
Alive unhealthy	26.8	31.6	32.7	41.2
Dry	15.1	8.9	23.7	20.5
Total	100	100	100	100

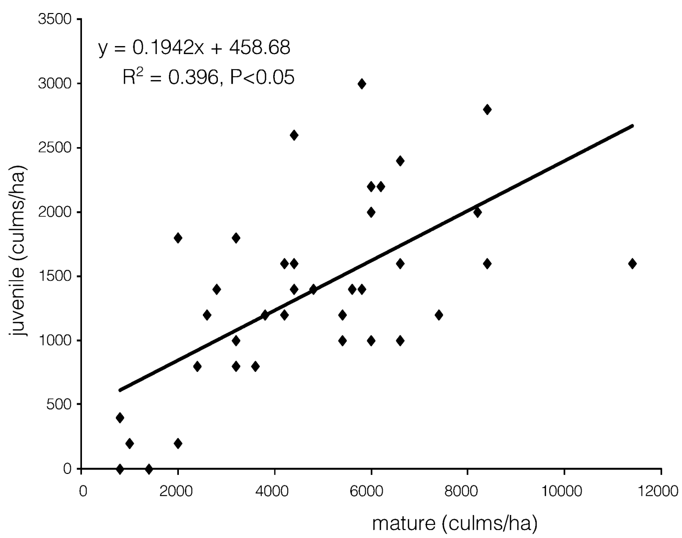

Figure 5. Relationship between the density of juvenile and mature culms using backward lineal regression analysis

on a stand with a density of 5000 mature otate culms/ha we predict a production of ca. 1430 juvenile culms/ha/yr. Every juvenile culm has an average weight of 5 to 6kg. Therefore, the results predict an estimated yield of 7 to 8tons/ha of bamboo fresh weight. Besides, mature culms can be sold as stakes at a price of US$0.10 to US$0.20 each. The bamboos not only provide income to peasant families, but also play an important role in regenerating the forest, restoring and maintaining fertility and the productivity of land, conserving soil moisture and reducing and preventing erosion and flood risks, as well as replacing unsustainable agricultural production activities (Christanty *et al.*, 1996; Singh and Singh, 1999; Ruiz-Pérez *et al.*, 2001).

Finally, grazing livestock break juvenile culms, eat the apical part of the new shoot, trample and graze seedlings completely. Stands that flower must remain undisturbed for at least 3 to 4 years to avoid damage to seedlings. However, cattle owners consider these recuperating stands an attractive range and introduce livestock. According to local people, this practice has already completely destroyed numerous stands. The control efforts should be directed towards integral management plans to avoid the deterioration of the *otatales*.

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