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Forest Ecology and Management 198 (2004) 75–88
Forest Ecology and Management
www.elsevier.com/locate/foreco

Growth impacts of *Psittacanthus angustifolius* Kuijt on *Pinus oocarpa* Schiede in Honduras

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Received 18 December 2003; received in revised form 8 March 2004; accepted 9 March 2004

Abstract

The mistletoe *Psittacanthus angustifolius* Kuijt (Loranthaceae) severely parasitizes *Pinus oocarpa* Schiede in southern Mexico and Central America causing growth loss and increased mortality of severely infected trees. The objectives of this study were to use stem analysis to evaluate the impacts of *P. angustifolius* on *P. oocarpa* in terms of height and volume growth of individual trees in Honduras and to evaluate a five-class mistletoe rating system for predicting the effects of this mistletoe on the growth of *P. oocarpa*. Two study sites in Honduras were selected based on incidence and severity of mistletoe infection. Thirteen dominant or codominant trees from each of three true mistletoe rating (TMR) classes: 0, no infection; 2, moderate infection; and 4, severe infection were selected. Stem analysis was conducted on the 78 selected trees to determine their height increment, volume increment, and specific volume increment. To evaluate growth reductions, each infected tree was paired with a healthy tree from the same site by height at time of infection for periodic height increment, age for periodic specific volume increment, and by volume at time of infection for periodic volume increment. To evaluate the mistletoe rating system 95% confidence intervals were constructed to compare means for height and volume increments between mistletoe infection classes for the last year of growth. Growth losses of over 50% were observed in terms of periodic volume increment and periodic specific volume increment during the last 3-year period prior to sampling for trees in TMR class 4 from both sites. Analysis of the effectiveness of the mistletoe rating system for predicting growth losses produced inconsistent results between sites because duration of infection, which was not a component of the rating system, influenced growth losses.
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Keywords: *Psittacanthus angustifolius*; Mistletoe; *Pinus oocarpa*; Honduras; Growth impacts; Stem analysis

1. Introduction

Mistletoes in the genus *Psittacanthus* (Loranthaceae) are obligate hemi-parasites that parasitize conifers, hardwoods, and other mistletoes (Kuijt, 1964, 1987; Lopez-De Buen and Ornelas, 1999; Vazquez Collazo and Geils, 2002). In the Americas, species of this genus are primarily distributed in the tropics and subtropics of Central and South America, but can be found from the temperate forests of northern Mexico (Kuijt, 1973) to as far south as Argentina (Graziano et al., 1967).

Species of *Psittacanthus* are considered to be primarily water and mineral parasites (Kuijt, 1964), relying on their hosts to provide all of their water and mineral requirements. Unlike dwarf mistletoes (*Arceuthobium* spp.) (Hawksworth and Wiens, 1996), *Psittacanthus* spp. produce their own carbohy-

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doi:10.1016/j.foreco.2004.03.047

drates through photosynthesis. Luttge et al. (1998) reported that the amount of photosynthate produced by *Psittacanthus robustus* Mart. was found to closely approximate that of its host in adjacent branches. Leaves of *Psittacanthus* spp. transpire at much higher rates (per unit leaf area) than the leaves of their hosts, thereby creating a high osmotic pressure gradient between the parasite and its host (Luttge et al., 1998). This allows the mistletoe to receive a disproportionate amount of water than infected host branch foliage found distal to branch infections. Therefore, when large, mature mistletoe plants occur on branches, the vigor of the host's foliage and the annual radial growth of the host branches are decreased distal to the infection locus of the parasite and eventual mortality of all host tissue distal to the infection locus often results (Kuijt, 1964; Vazquez Collazo and Perez, 1982, 1986). Parasitism by *Psittacanthus* spp. may cause reduced growth of their hosts through loss of host foliage and through loss of water and mineral resources (Lezama and Melgar, 1999; Vazquez Collazo and Perez, 1982, 1986).

Kuijt (1987) described *Psittacanthus angustifolius* Kuijt from collections on *Pinus* sp. in northern Nicaragua, but its distribution in Nicaragua is poorly known. It has been reported to be common in the pine forests of Honduras (Beatty et al., 1999; Lezama and Melgar, 1999; Mathiasen et al., 2000a), central Guatemala and Chiapas, Mexico (Mathiasen et al., 2000b) (Fig. 1). It has also been observed in the pine forests of northwestern El Salvador (Mathiasen et al., 2003). *P. angustifolius* primarily parasitizes *Pinus oocarpa* Schiede (Mathiasen et al., 2003), but it has also been reported on *P. caribaea* var. *hondurensis* (Sënëcl) Barr. et Golf. (Mathiasen et al., 2002), *P. maximinoi* H.E. Moore (Mathiasen et al., 2000a), *P. tecunumanii* (Schw.) Eguiluz et Perry and *Psidium guieense* SW (Melgar et al., 2001).

P. angustifolius usually occurs in discrete infestations ranging in size from a few individual trees to hundreds of trees spread out over several kilometers. It has been reported in most of the Departments in Honduras (Mathiasen et al., 2003). However, *P. angustifolius* has a low overall incidence in the pine forests

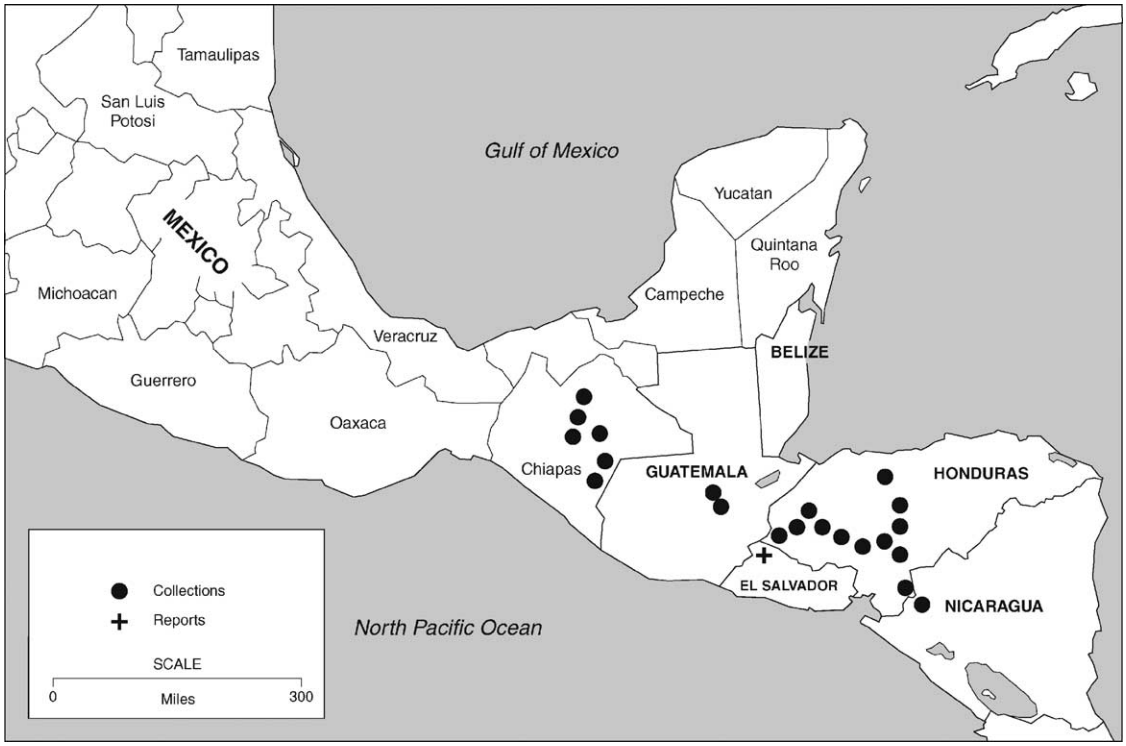

Fig. 1. Distribution of *P. angustifolius* in Mexico and Central America.

of Honduras. A roadside reconnaissance in Honduras of approximately 1000 km found less than 5% of the area surveyed was infested with *P. angustifolius* (Beatty et al., 1999).

Mistletoe rating systems are typically used for estimating the severity of mistletoe infection on individual trees and within forests. The severity of infection is then used to estimate the amount of growth loss experienced due to mistletoe infection. It is important to understand the relationship between severity of infection as indicated by the rating system and growth reductions experienced by trees or forests so that management priorities can be initiated to reduce the growth effects of mistletoe infection (Hawksworth, 1977). A number of different mistletoe rating systems have been used for estimating the effects of *Psittacanthus* spp. on the growth of pines in Mexico and Central America (Vazquez Collazo and Perez, 1982, 1986; Beatty et al., 1999; Lezama and Melgar, 1999; Martinez and Melgar, 2000). Radial growth reductions at diameter breast height (dbh, 1.37 m above the ground) caused by *P. angustifolius* on *P. oocarpa* have been reported in Honduras and mortality of severely infected pines has been observed (Beatty et al., 1999; Lezama and Melgar, 1999; Martinez and Melgar, 2000). Beatty et al. (1999) sampled 5- and 10-year radial growth of trees with various levels of mistletoe infection near Lepaterique (Department Francisco Morazan). They used a mistletoe rating system modified from Vazquez Collazo and Perez (1986) where healthy trees were rated as 0, moderately infected trees were rated as 1, and severely infected trees were rated as 2. They found reduced 5- and 10-year radial growth with increasing levels of infection. Martinez and Melgar (2000) used a similar mistletoe rating system as Beatty et al. (1999) and compared the breast height radial growth of healthy and infected trees at a site near Yamaranguila (Department Intibuca). They also found significant reductions in both 5- and 10-year radial growth for moderately and severely infected trees. Lezama and Melgar (1999) sampled 5- and 10-year breast height radial growth at the same site as Beatty et al. (1999) and found significantly less growth in infected versus healthy trees.

P. oocarpa is the most important timber species in Honduras as it represents approximately 75% of the standing volume on the over 2 million ha of Honduran pine forests (United Nations Development Program, 1968; Markkola et al., 1996). *P. oocarpa* is the most commercially important pine in Honduras and is intensively managed for timber production. While *P. angustifolius* is not a widespread disease in Honduran pine forests, in some localities it is common and severely parasitizes *P. oocarpa*. Without a better understanding of the impacts of *P. angustifolius* on the volume and height growth of infected *P. oocarpa*, management decisions based on cost–benefit analysis are impractical. Although radial growth reductions have been reported for moderate to severely infected trees with *P. angustifolius* in Honduras, no studies have been conducted to evaluate the impact this parasite has on volume and height growth, impacts of infection through time, or the effectiveness of mistletoe rating systems for evaluating the growth losses associated with this mistletoe. Therefore, this study was initiated to provide information on the effects of *P. angustifolius* on the volume and height growth of *P. oocarpa*. The objectives of this study were to use stem analysis to evaluate the impacts of *P. angustifolius* on *P. oocarpa* in terms of height and volume growth of individual trees through time and to evaluate a five-class mistletoe rating system for predicting the effects of *P. angustifolius* on the growth of individual *P. oocarpa* trees in Honduras.

2. Study areas

Possible study sites were selected based on the incidence and severity of *P. angustifolius* infection and the ability to acquire permission and permits to conduct destructive sampling of trees for stem analysis from landowners and from the Honduran Forest Service (AFE-COHDEFOR). Although several possible study sites on private land were considered for use in this study, permission to cut trees could not be obtained from the landowners. Therefore, only two sites were selected: (1) a privately owned pine forest near the town of Yamaranguila (Department Intibuca), and (2) a site managed by AFE-COHDEFOR near the town of Lepaterique (Department Francisco Morazan) (Fig. 2).

The Yamaranguila site consisted of about 35 ha located on private property approximately 3.5 km north–northeast of Yamaranguila (Fig. 2). Trees sampled were found on or near the top of a ridge

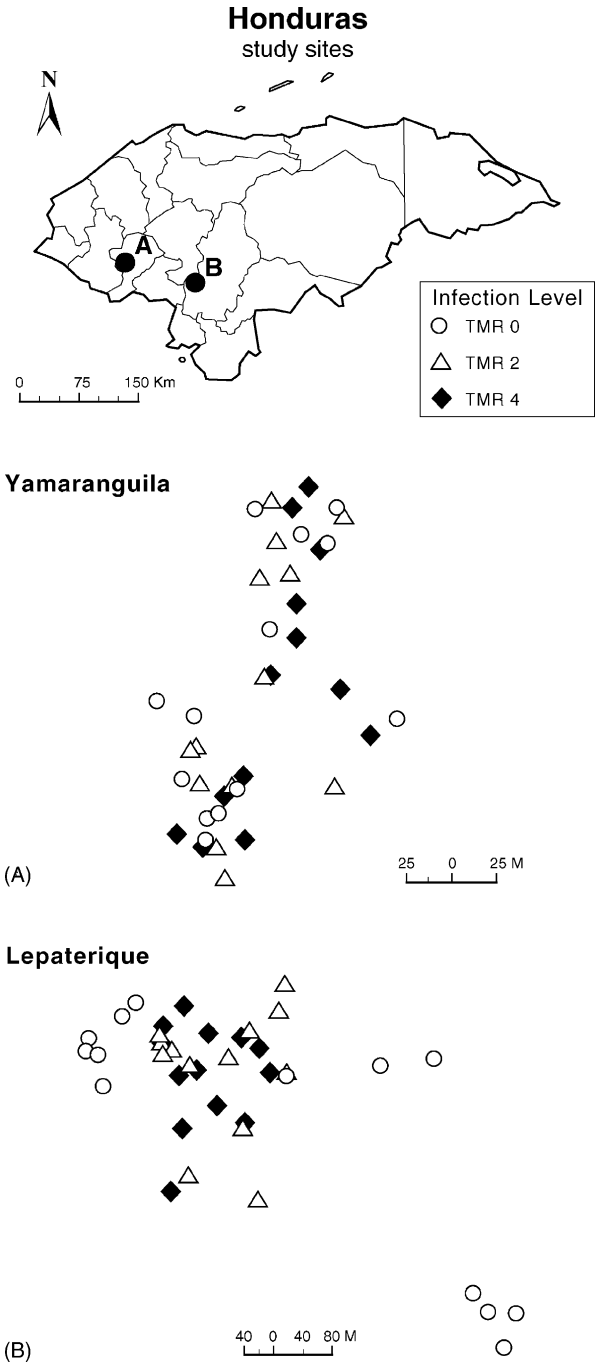

Fig. 2. Approximate locations of the Yamaranguila (A) and Lepaterique (B) study sites in central Honduras and the relative locations of individual sampled trees and their true mistletoe ratings (TMR) within each site.

running north in a *P. oocarpa* forest savanna at an average elevation of 1820 m. This site had an average basal area of 14.7 m^2/ha. This site was located approximately 0.5 km northeast of the study area described by Martinez and Melgar (2000) and is an extension of the same mistletoe infestation found on the Yamaranguila site. Martinez and Melgar (2000) estimated the percentage of pines infected in their study area and used the mistletoe rating system described by Beatty et al. (1999) to estimate severity of mistletoe infection. Their study site had 50% of the pines infected with *P. angustifolius* with an average mistletoe rating of 0.6 on a scale of 0–2.

Overstory species in the Yamaranguila site consisted almost entirely of *P. oocarpa* mixed with an occasional oak (*Quercus* sp.). Understory vegetation included a mixture of grasses, pine regeneration, and small oaks. Soils were thin, sandy, and poorly drained on top of a sandstone bedrock formation. The area experienced heavy grazing pressure by cattle and horses at the time of the study and presumably had for decades. The history of past timber harvests was unknown, but a few large, non-decomposed stumps in the study site indicated that light harvesting had taken place in the past 5–10 years. The stand had natural regeneration and was uneven-aged; the oldest trees were approximately 90–110 years old.

The Lepaterique site consisted of about 120 ha located on federal lands managed by AFE-COHDEFOR, located approximately 0.5 km southeast of Lepaterique (Fig. 2). This property was once a military training ground that has been converted into a training center known as the Centro de Capacitacion Forestal (CECAFOR). Trees sampled at this site were on a plateau in a *P. oocarpa* forest savanna at an average elevation of 1500 m. This site had an average basal area of 11.4 m^2/ha. The entire CECAFOR area had been sampled for incidence of *P. angustifolius* by Lezama and Melgar (1999); 25% of the pines were infected with an average mistletoe rating of 0.5 on a scale of 0–5.

Overstory species consisted almost entirely of *P. oocarpa* mixed with occasional oaks (*Quercus* sp.). Understory vegetation included a mixture of pine regeneration, grasses, and small oaks. Soils were thin, sandy, and poorly drained on top of a sandstone bedrock formation. The area had a history of heavy livestock grazing pressure by cattle and horses which also

occurred at the time of the study, despite recently implemented efforts to exclude livestock. Many dominant and codominant trees had been utilized for resin collection, which were not used for this study because the resin collection process may have affected the growth of these trees. Part of this site had been thinned to remove trees severely infected with *P. angustifolius* in the year 2000 as part of a long-term mistletoe control project; these areas were avoided when selecting trees for this study. Based on the distribution of *P. angustifolius* infection, damage to trees because of resin collection, and thinning in mistletoe-infested areas, only about 60 ha of the CECAFOR site were used for this study. The site had natural pine regeneration and was uneven-aged; the oldest trees were approximately 60–75 years old.

3. Methods

Tree selection at each study site was based on crown class and severity of *P. angustifolius* infection. Thirteen dominant or codominant trees from each of three true mistletoe rating classes: 0, no infection; 2, moderate infection; and 4, severe infection, were selected for stem analysis; a total of 39 trees at each study site.

The TMR classifications were assigned using the following procedure:

(1) The live crown of each tree was divided into halves of equal length and each half rated separately as follows:
   - If no mistletoe infection was found in a half, it was rated as 0.
   - If mistletoe was present in a half but the mistletoe foliage comprised less than 50% of total foliage (including host foliage) in that half, it was rated as 1.
   - If mistletoe foliage in a half comprised more than 50% of total foliage, it was rated as 2.
   - If a single mistletoe plants' foliage occupied both crown halves, foliage found in each half was evaluated separately.

(2) The ratings for each half were summed to obtain a total from 0 to 4.

This system is similar to that proposed by Lezama and Melgar (1999), but differs in that an additional point was not added if one or more infections occurred on the main stem of the tree. This modification was made because it was assumed that stem infections did not impact growth reductions more than did branch infections.

At each sampled tree, a number of measurements were taken. Tree measurements included dbh (nearest 0.1 cm) measured with a diameter tape, and the UTM location and elevation of each tree was measured with a hand-held Magellan GPS unit. In addition, the stand basal area in the vicinity of each tree was measured using a relaskop from a point 1 m north of the tree (nearest 1 m^2/ha). Every attempt was made to select trees at each site so that trees from all TMR classes were intermixed and in close proximity to each other in order to minimize potential site-related confounding factors that might influence rates of tree growth.

Trees were then felled and the base of each mistletoe plant and its adjacent host tissue was collected and marked with a unique number corresponding to the tree and sequence in which it was collected. Mistletoe infections were collected so that the age of each infection could be estimated (see below) to determine the duration of infection for each tree.

In preparation for stem analysis, cross-sections (approximately 6 cm thick) were collected from the main bole of each tree at 30 cm and 1.37 m above the ground and then at 2 m intervals to within 3 m of the top of each tree. To attain better height estimates of each tree during the years immediately prior to felling, the final three sections were taken at 1 m intervals. In all cases, each cross-section was collected either at the exact measurement described above or at the nearest internode. The height of each cross-section was measured to the nearest centimeter. Cross-sections were also assigned a number designating the tree and cross-section location.

Cross-sections were taken to the Escuela Nacional de Ciencias Forestales (ESNACIFOR) for processing. Processing involved drying and sanding cross-sections using a series of sandings using 80–400 grit sandpaper. One average radius (long radius plus short radius/2) was marked on cross-sections with less than a 20% difference between the long and short radii, and two average radii were marked on cross-sections where this difference exceeded 20%. Typically, the lowest one or two cross-sections for each tree were measured along two average radii because *P. oocarpa* frequently has irregularly shaped lower trunks.

Ring counts were conducted for each cross-section and true rings were marked along each radius. True ring identification was complicated because *P. oocarpa* is prone to false ring formation. In addition, trees experiencing severe growth reductions due to *P. angustifolius* infection were prone to form locally absent rings. To identify false rings, individual rings were followed around the entire section and examined closely with a 10× hand lens to identify signs of false rings as described by Stokes and Smiley (1996). To identify locally absent rings, cross-sections were closely examined for true rings that were not found along marked radii. The locally absent rings were then indicated along the marked radii. True ring widths were then measured to the nearest 0.1 mm using Plasti-cal digital calipers. Measurements of true rings were made from the pith outward. In cases where true rings were locally absent along a marked radius, a ring width value of 0.01 mm was assigned to designate where locally absent rings occurred because a non-zero number was required for subsequent stem analysis calculations. In cases where two average radii were measured, a mean ring width was calculated for each true ring and used for stem analysis calculations. All ring width data were entered into a Microsoft Excel spreadsheet for analysis.

The following stem analysis variables were obtained from each tree and year: height, total volume, volume increment, cambial surface area, and specific volume increment (Duff and Nolan, 1953, 1957). Annual heights between cross-sections were calculated using Carmean's equation (Carmean, 1972) and heights between the top cross-section and the top of the trees were calculated using Newberry's revision to the Carmean equation (Newberry, 1991). Annual total volume was calculated assuming a conical frustum between cross-sections for portions of annual growth represented by two cross-sections (Piene et al., 1981). Annual total volume was calculated assuming a cone for portions of annual growth represented by an individual lower section and an upper height value (Piene et al., 1981). Volume increment was calculated by subtracting the previous year's total volume from the current year's total volume. Annual cambial surface area was calculated similarly to annual total volume, using surface area rather than volume formulas. Specific volume increment (SVI) is defined as the annual volume increment divided by the cambial surface area that produced it (Duff and Nolan, 1957) and was calculated by dividing the current year's annual volume increment by the previous year's annual cambial surface area. Specific volume increment allows for direct comparison of growth rates of trees of different sizes and is a sensitive measure for assessing growth responses to forest pest activity (Piene et al., 1981).

All collected mistletoe infections were taken to ESNACIFOR for processing. Processing involved drying, cross-sectioning, and a series of sandings using 80–400 grit sandpaper. The age of each mistletoe infection was determined by identifying the initial year of infection in the host tissue of each cross-section. Then annual rings produced in the host after initial infection were counted to determine the infection age. This technique was illustrated by Kuijt (1970) and is based on the fact that haustorial tissue of *Psittacanthus* does not extend beyond host xylem tissue formed during the year of initial infection. The age of each mistletoe infection was recorded and the year of infection for the oldest infection on each tree was used as the year of initial infection during subsequent analysis. However, the age of the oldest infection on some trees was likely earlier than that estimated by this procedure because in some cases older infections may have fallen off due to branch breakage.

3.1. Data analysis

To examine growth losses associated with *P. angustifolius* infection, trees were paired in groups of healthy and moderately infected trees and healthy and severely infected trees by similar ages to compare 3-year SVI growth reductions. Age was chosen as the pairing factor for SVI comparisons because SVI is not tree size sensitive, but may be age sensitive. Pairing was conducted by similar heights at time of infection to compare 3-year periodic height increment reductions because trees of similar heights in a given year are likely to experience similar subsequent height growth. Pairing was conducted by similar volume at time of infection to compare 3-year periodic volume growth because current volume is the best predictor of future volume growth. For SVI comparisons the oldest healthy tree was paired with the oldest TMR 2 and TMR 4 trees of similar age at each study site. Then the next oldest healthy tree was paired with the next oldest

TMR 2 and TMR 4 tree of similar age and so forth until all of the trees were paired. To pair trees by height at time of infection and by volume at time of infection, the height and volume values for each infected tree were compared to healthy trees from the same site and healthy trees with similar values were chosen for pairs. This process required that some trees be eliminated from the analysis as appropriate pairs were not found for all infected trees.

In order to examine the impact of the duration of mistletoe infection on tree growth, 3-year periodic growth was examined. Moderately and severely infected trees (TMR 2 and 4) were individually paired with healthy trees as described above. In each case, average 3-year increments were examined for individual trees for one 3-year period prior to infection and for all complete 3-year periods after infection occurred. Growth reductions (Gr) were calculated for each pair of trees for each period examined using Eq. (1) where the 3-year periodic average for the healthy tree in each pair was treated as Gie and the 3-year periodic average for the infected tree in each pair was treated as Gio (Mallett and Volney, 1999):

$$\mathrm{Gr} = \frac{\mathrm{Gie} - \mathrm{Gio}}{\mathrm{Gie}} \tag{1}$$

Individual pre- and post-infection comparisons were time synchronous. However, averages based on all pairs from each site were not synchronous as initial year of infection differed between trees. For example, the first 3-year post-infection periodic growth loss for a healthy/infected pair with an initial infection in 1985 of the infected tree was calculated by comparing growth of the healthy tree for 1985–1987 to the 1985–1987 growth of the infected tree. Then this growth loss was averaged with the first 3-year periodic growth loss from the other healthy/infected pairs. However, the growth loss for each of the healthy/infected pairs was calculated based on the specific initial infection date for each of the infected trees. Therefore, as the time since infection increased, pairs of healthy and infected trees that had later initial infections were eliminated from the analyses. Differences in sample sizes between the growth analyses was due both to the availability of appropriate pairs for each growth analysis paring factor (age, height, and volume) and to the loss of pairs from each analysis as the duration of infection increased.

The five-class TMR system was evaluated for both sites in terms of its effectiveness in predicting height increment and volume increment reductions. Because the TMR evaluations were made immediately prior to felling each tree, these ratings only applied to mistletoe infection severity at that point in time. Therefore, 95% confidence intervals were constructed for each study site to compare differences between groups of trees for average height increment and volume increment for the final year of growth between all trees. Trees were grouped into the following TMR classes: 0, 2, and 4. Confidence intervals were constructed using JMP statistical software (Sall et al., 2001).

4. Results

Trees at the Yamaranguila site in each of the three TMR classes (0, 2, and 4) sampled were intermixed and in close proximity to each other (Fig. 2). Healthy trees at the Lepaterique site were difficult to find within the infection center where the TMR 2 and 4 trees were sampled. While occasional healthy trees did occur within the infection center, in almost all cases those trees showed signs of resin collection and were unsuitable for use in this study. As a result, healthy trees were found predominately on the periphery of the infection center (Fig. 2). Although some of the healthy trees were as far away as approximately 300 m from the infected trees, they were all in the same site based on topography, stand density, and stand composition.

Examining 3-year periodic growth reductions for height increment, volume increment, and SVI provided information on the importance of the duration of infection on tree growth. This analysis illustrated that duration of infection had a substantial effect on growth reductions.

Height increment reductions demonstrated large standard errors and an increasing trend in periodic height increment reductions as the duration of infection increased at both study sites (Fig. 3). Average growth reductions estimated using height increment increased from 12% for infected trees for the first 3 years after infection occurred to over 40% for trees that had been infected for 15–17 years for TMR class 4 at the Yamaranguila site (Fig. 3). Average growth reductions estimated using height increment increased

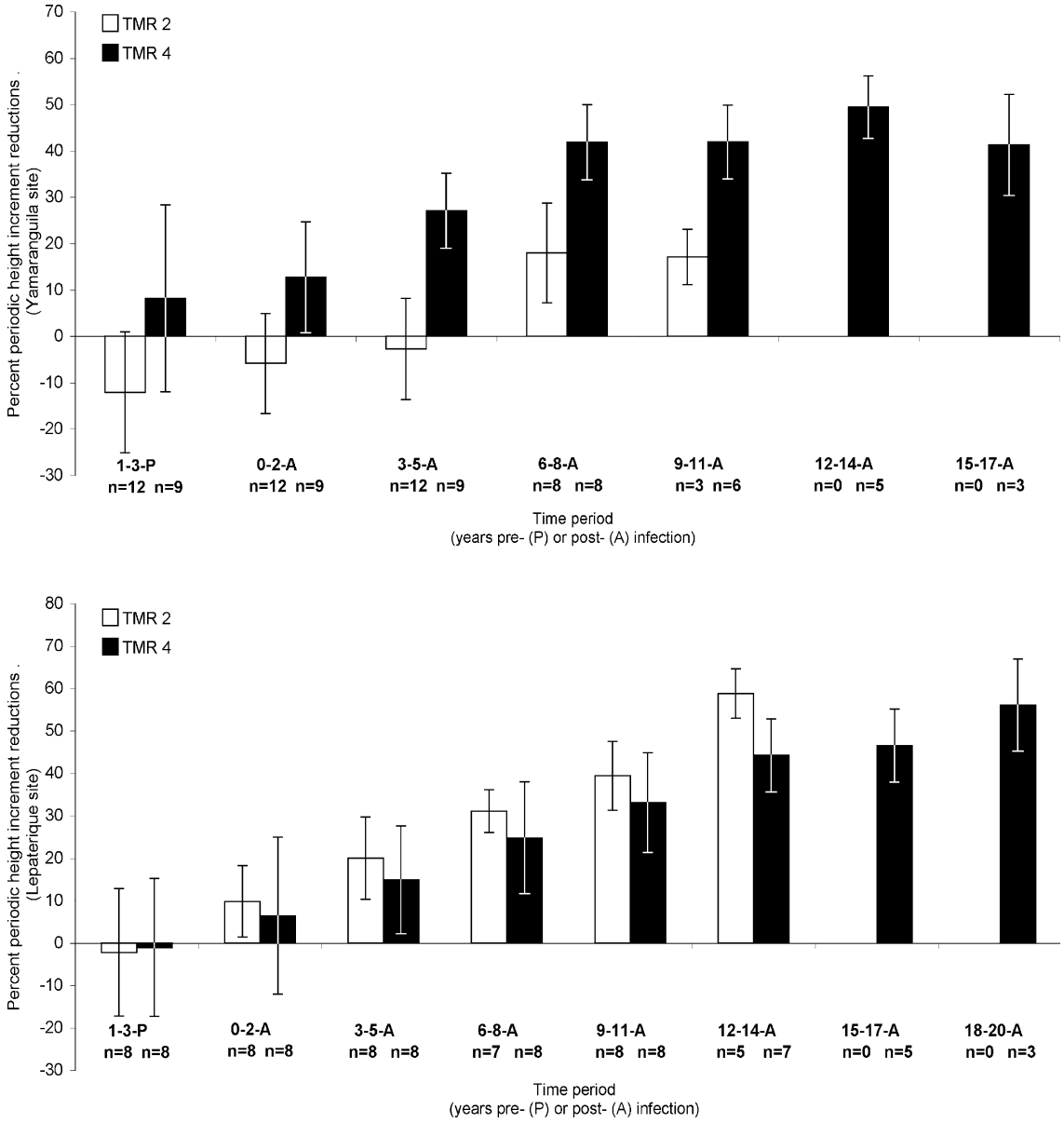

Fig. 3. Average percent reductions of periodic height increment growth with standard error bars for 3-year periods beginning 3 years prior to infection and ending at the year of sampling for the Lepaterique and Yamaranguila sites. The number of pairs (*n*) utilized for each average percent reduction is shown under each bar.

from 14% for infected trees 3–5 years after infection occurred to over 50% for trees that had been infected for 18–20 years for TMR class 4 at the Lepaterique site (Fig. 3).

Note that the number of paired trees decreased as the duration of infection increased because pairs of trees with a later initial infection were eliminated from the analysis. For example, the four pairs of trees with an infected tree that had only been infected for 5 years could not be used for the 6–8-year infection period. Therefore, the 3–5-year time period was represented by 12 pairs in the TMR 2 class at the Yamaranguila site

and only eight trees for the 6–8-year period, the 9–11-year period only had three trees, and no selected pairs had durations of infection greater than 11 years (Fig. 3). For the same reason, sample sizes for the following analyses of growth loss exhibited reductions as the duration of infection increased.

Periodic volume increment reductions from both sites also increased as the duration of infection increased (Fig. 4). Average periodic volume increment reductions of infected trees from both sites for the 3-year period prior to infection were negative, except for the TMR 2 trees from the Lepaterique site. This indicated that these infected trees were accumulating more volume during this period than were the healthy trees. By the 6–8-year period after infection, average periodic volume increment reductions for all infected

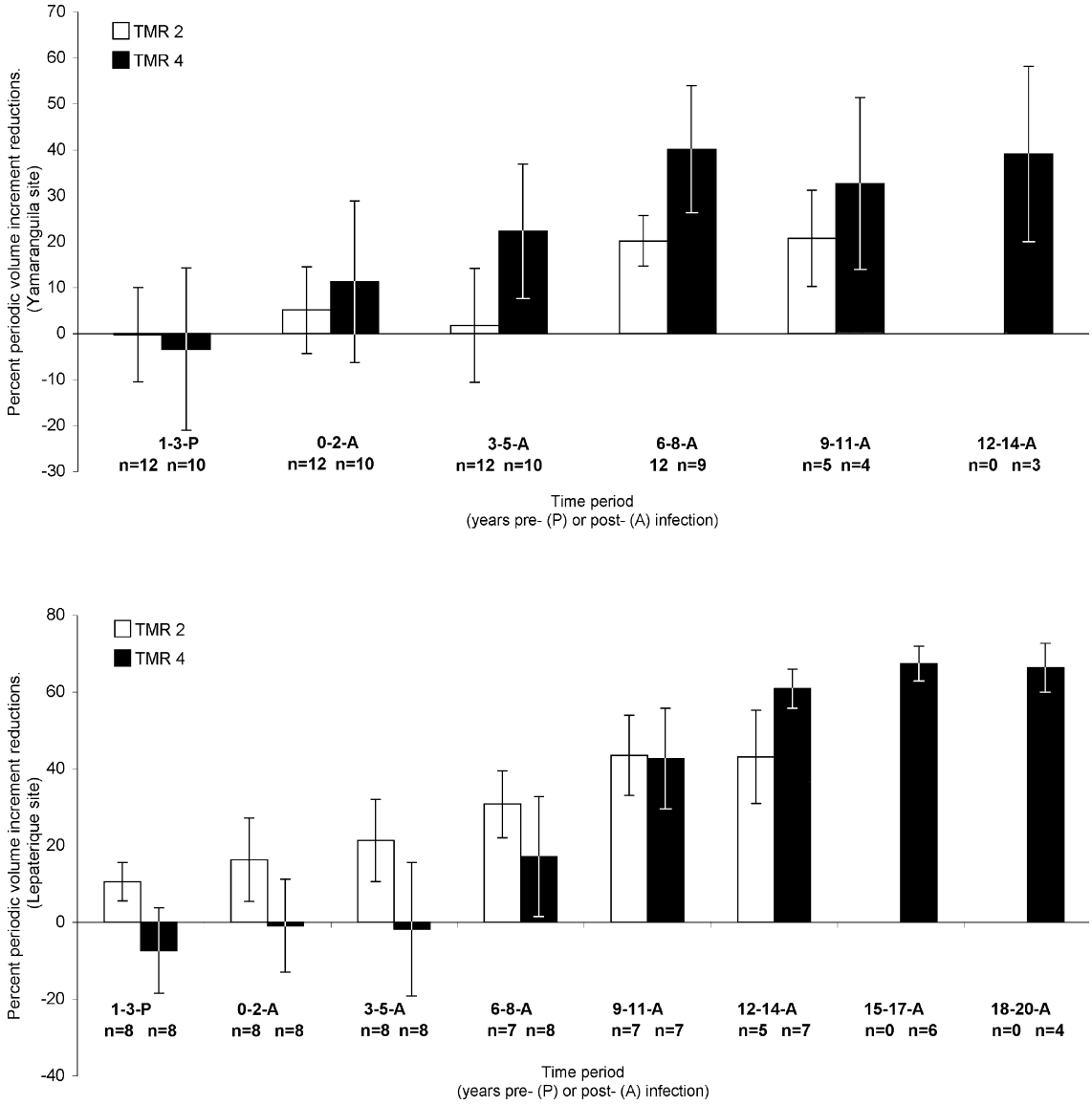

Fig. 4. Average percent reductions of periodic volume increment growth with standard error bars for 3-year periods beginning 3 years prior to infection and ending at the year of sampling. The number of pairs (n) utilized for each average percent reduction is shown under each bar.

trees from both sites were positive and continued to increase as the duration of infection increased. Average growth reductions estimated using periodic volume increment increased from 23% for infected trees 3–5 years after infection occurred to approximately 40% for trees that had been infected for 12–14 years for TMR class 4 at the Yamaranguila site (Fig. 4). Average growth reductions estimated using periodic volume increment increased from 18% for infected trees 6–8 years after infection occurred to over 60% for trees that had been infected for 18–20 years for TMR class 4 at the Lepaterique site (Fig. 4).

Periodic SVI reductions for both sites in both TMR 2 and 4 classes had an upward trend from the 3-year period prior to infection through the last year of growth (Fig. 5). Periodic SVI reductions increased at both sites as duration of infection increased. At the Lepaterique site average periodic SVI reductions were 14% for the TMR 2 class in the 3-year period prior to infection, indicating that these trees were experiencing

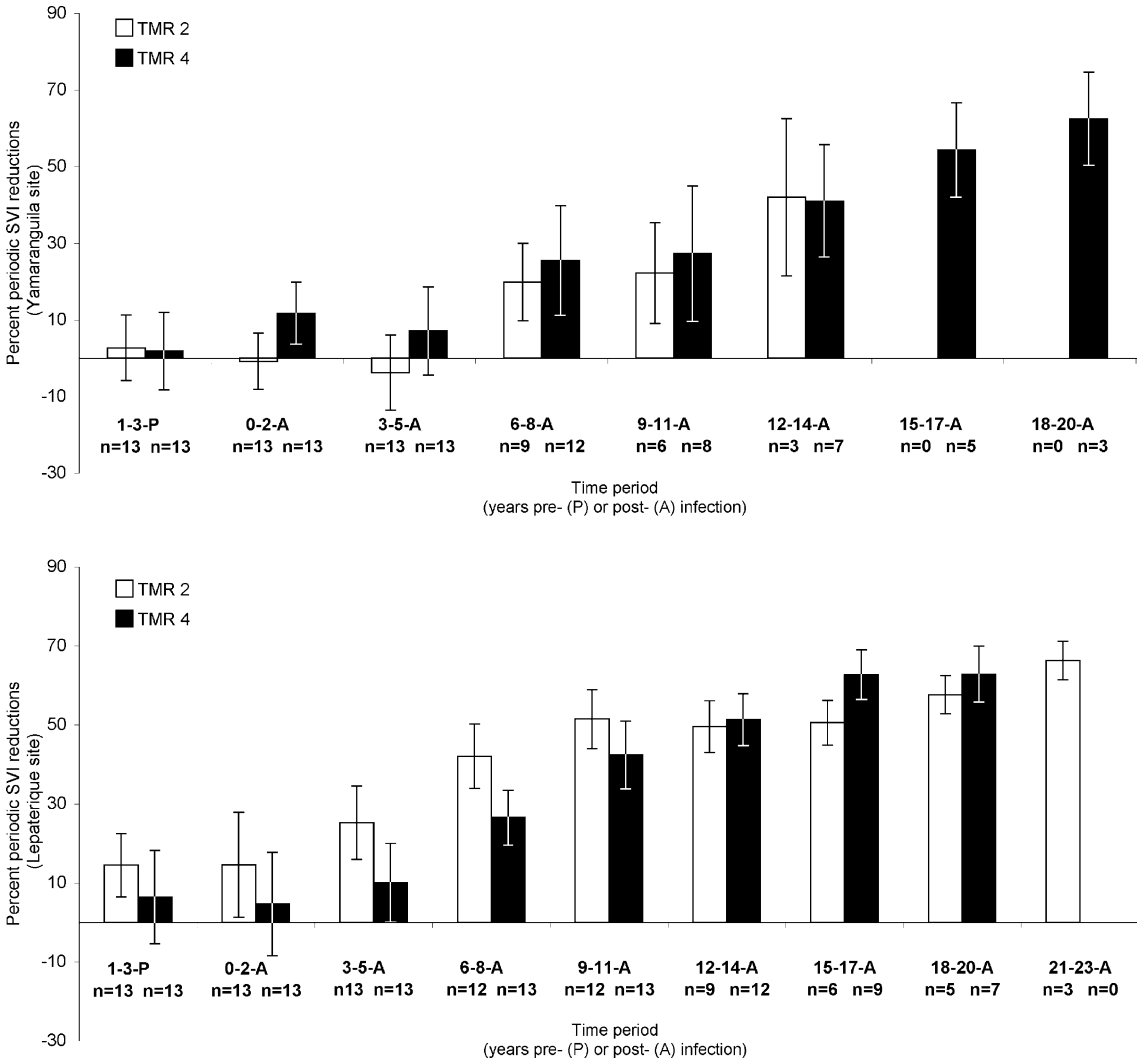

Fig. 5. Average percent reductions of periodic specific volume increment (SVI) growth with standard error bars for 3-year periods beginning 3 years prior to infection and ending at the year of sampling. The number of pairs (n) utilized for each average percent reduction is shown under each bar.

slightly reduced growth when compared to the healthy trees prior to infection. Growth reductions estimated using periodic SVI increased from 26% for infected trees 6–8 years after infection occurred to over 60% for trees that had been infected for 18–20 years for TMR class 4 at the Yamaranguila site (Fig. 5). Growth reductions estimated using periodic SVI increased from 10% for infected trees 3–5 years after infection occurred to over 60% for trees that had been infected for 18–20 years for TMR class 4 at the Lepaterique site (Fig. 5).

Differences in averages between TMR 2 and TMR 4 for all infected trees from both sites for periodic height increment, periodic volume increment, and periodic SVI exhibited a great deal of overlap in their standard errors within each 3-year period, suggesting that duration of infection was a better indicator of the effects of mistletoe infection on tree growth reductions than were mistletoe ratings.

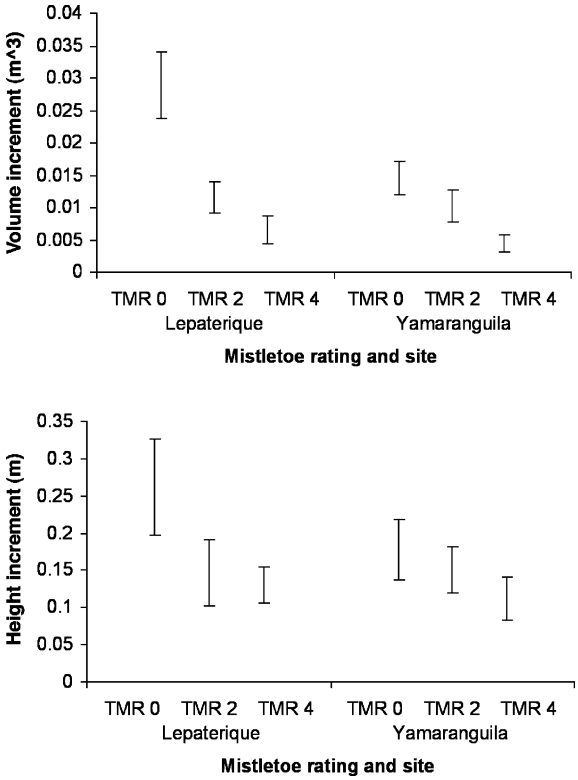

Fig. 6. Ninety-five percent confidence intervals of group averages of height increment (m) and volume increment (m^3) between true mistletoe ratings (TMR) 0, 2, and 4 during the final year's growth of trees at the Lepaterique and Yamaranguila sites.

The mistletoe rating system used in this study reflected growth reduction trends associated with mistletoe infection in the last year of growth in all cases. The 95% confidence intervals illustrated a reduction in mean volume and height increments as the severity of infection increased (Fig. 6). However, the 95% confidence intervals exhibited some overlap between TMR 2 and TMR 4 from the Lepaterique site for height increment and volume increment. At the Yamaranguila site, overlap in 95% confidence intervals was observed between TMR 0 and TMR 2, as well as TMR 2 and TMR 4 in terms of height increment and between TMR 0 and TMR 2 in terms of volume increment. No other 95% confidence intervals were found to overlap between mistletoe rating classes (Fig. 6). Trends in mean growth reduction differed between sites. The Lepaterique site exhibited a greater reduction in both height and volume increments between TMR 0 and 2 than was observed at the Yamaranguila site. At the Yamaranguila site trees rated as TMR 2 usually had a lower mean age (11.6 years) than did trees rated as TMR 4 (15.5 years) and infection means were younger than those found at the Lepaterique site. At the Lepaterique site the difference in mean age of infection between TMR 2 (18.9 years) and TMR 4 (19.2 years) was small.

5. Discussion

The results of this study indicated that duration of mistletoe infection is the most important factor in determining the magnitude of growth reductions of *P. oocarpa* associated with *P. angustifolius* infection at both study sites (Figs. 3–5). Periodic height increment reductions showed a general increase in magnitude with increasing duration of infection (Fig. 3). However, the reductions in periodic height increment decreased as duration of infection increased after 15 years of mistletoe infection at the Yamaranguila site in the TMR 4 class. The reason for this decrease in height increment is unclear. Perhaps the differences in periodic height growth reduction between the two sites are related to small sample sizes as the length of infection increased; only three pairs of healthy and infected trees were sampled that had infections that were 15–17 years old in the TMR 4 class at the Yamaranguila site (Fig. 3).

This study demonstrated that infection by *P. angustifolius* can substantially reduce the height growth of infected pines. Periodic height increment reduction was greater than 40% at both sites for trees that had been infected for over 12 years in the TMR 4 class.

Periodic volume increment also demonstrated an increasing trend in growth reductions as duration of infection increased. The magnitude of this volume decrease was similar (rarely exceeding one standard error) both for TMR 2 and 4 trees within sites and between sites for the same 3-year periods (Fig. 4).

Volume increment reductions due to infection by *Psittacanthus* have been previously reported for pines in Michoacan, Mexico (Vazquez Collazo and Perez, 1982). However, that study used diameter increment to estimate potential volume production for healthy and *Psittacanthus*-infected pines. Volume growth reductions reported by Vazquez Collazo and Perez (1982) were greatest for *Pinus montezumae* Lamb. (0.08 cm^3/tree per year) and least for *P. teocote* Schl. and Cham. and *P. leiophylla* Schl. and Cham. (0.02 cm^3/tree per year). The reduction in volume increment for *P. leiophylla* was estimated to represent half the potential volume production for this species in Michoacan (Vazquez Collazo and Perez, 1982). However, that study only examined healthy versus infected trees and did not provide information on the effects that different levels of *Psittacanthus* infection caused in the pine species examined. In contrast, this study has provided specific data on the effects of *Psittacanthus* infection on the volume increment of *P. oocarpa* for the two study sites sampled in Honduras.

We did not report annual volume losses on a per tree basis because these figures would probably be misleading because they would be based on infection-related volume losses and on the size of the tree. For example, a given amount of volume loss for a small tree would represent a higher percentage loss of potential volume growth than the same amount of volume loss in a larger tree. Instead, growth losses were reported on a percentage basis. Our results demonstrated that growth losses exceeded 60% of the potential volume growth for dominant and codominant *P. oocarpa* that have been infected for over 18 years at some locations in Honduras (Fig. 4). However, the volume reductions we found may have underestimated volume reductions because mortality among severely infected trees was observed at each site. Because we only examined trees that were alive at the time of sampling, dead trees that may have suffered even greater growth reductions were not sampled. Therefore, our sample represented a "best case scenario" for growth reductions based only on the living trees sampled at each site. For example, if trees had experienced mortality after 10 years of infection, 5 years prior to sampling was conducted they would not have been sampled, and therefore, the growth reductions they were experiencing during those 5 years would not have been accounted for in this study.

Periodic SVI also clearly demonstrated that as duration of infection increases, periodic SVI reductions increase (Fig. 5). This pattern was consistent at both of the study sites sampled. Growth reductions estimated using periodic SVI were more than 60% for trees that had been infected for more than 18 years for TMR 4 class at both sites which illustrated the large effect *P. angustifolius* infection has on the potential growth of *P. oocarpa*. Even trees rated as TMR 2 that had been infected more than 12 years at the Lepaterique site had an average of nearly 60% less growth than healthy trees.

Evaluation of the five-class TMR system we used indicated that it was an inconsistent estimator for evaluating the effects of mistletoe infection on *P. oocarpa*. The expected trend was observed, with final years' observed growth (as measured by height and volume increments) exhibiting a downward trend in mean values as severity of infection increased from TMR 0 to TMR 4 (Fig. 6). However, the trends were different between sites. The Yamaranguila site exhibited a gradual reduction in height and volume increment from TMR 0 to TMR 2 and from TMR 2 to TMR 4. In contrast, the Lepaterique site exhibited a larger drop in mean height and volume increment from TMR 0 to TMR 2 than from TMR 2 to TMR 4. The difference in trends between sites can be explained by the mean infection duration within TMR classes at each site. Trees in the TMR 2 class at the Lepaterique site had been infected longer than those in the TMR 2 class at the Yamaranguila site and based on the 3-year periodic growth reduction analysis above would be expected to have experienced greater growth reductions. The mistletoe infection rating system we used did not consider age of infection in its classification of trees into TMR groupings. A rating system which correlates well with duration of infection would be more likely to reflect growth reductions. Therefore, rating systems should be

developed that account for duration of infection. This could be accomplished by placing more importance on individual, larger (older) mistletoe plants than on multiple, smaller (younger) mistletoe plants in a rating system. Future research should be conducted to test alternative mistletoe rating systems that somehow incorporate duration of infection.

If the growth reductions for *P. oocarpa* reported from the sites we sampled are representative of other locations in Honduras, infection by *P. angustifolius* is responsible for a substantial loss of potential growth of this commercially important species in trees infected for several years. Therefore, management of this mistletoe should be considered wherever it occurs in stands managed for timber production. Management could include removal of severely infected trees and/or pruning of branches infected with large mistletoe plants to reduce the level of infection in stands and on trees (Beatty et al., 1999; Lezama and Melgar, 1999; Martinez and Melgar, 2000).

Acknowledgements

The authors appreciate the assistance of Dr. Jose Melgar and the Escuela Nacional de Ciencias Forestales, Siguatepeque, Honduras, for the use of equipment, lab facilities, and housing while this study was conducted in Honduras.

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