Developing techniques for monitoring forest tent caterpillar populations using synthetic pheromones

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Abstract—To effectively monitor forest tent caterpillar, *Malacosoma disstria* Hübner (Lepidoptera: Lasiocampidae), populations using sex pheromone baited traps, we field-tested pheromone dispenser (lure) type, lure age, and trap design using (*Z,E*)-5,7-dodecadienal:(*Z,Z*)-5,7-dodecadienal (100:1). Rubber septa lures, polyurethane lures, and two trap types [sticky-type pheromone traps (Wing Trap I) and bucket-type pheromone traps (Universal Moth trap)] were evaluated. Traps baited with polyurethane lures produced higher trap catches and lower zero-catch frequencies than did rubber septa traps. There was no detectable difference in trap catch among polyurethane lures aged 0–28 days. Wing traps reached a functional saturation point in outbreak *M. disstria* populations and caught fewer moths than Universal traps in nonoutbreak populations. A nonsaturating trap such as the Universal trap in conjunction with the polyurethane lure should be effective for monitoring *M. disstria* populations.

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Résumé—Pour suivre efficacement des populations de livrées des forêts, *Malacosoma disstria* Hübner (Lepidoptera : Lasiocampidae), au moyen de pièges garnis de phéromone, nous avons testé sur le terrain le type de distributeur (leurre), l‘âge du leurre et le design du piège avec du (*Z,E*)-5,7-dodécadienal : (*Z,Z*)-5,7-dodécadienal (100 : 1). Des leurres à septums de caoutchouc, des leurres de polyuréthane et deux types de pièges [(pièges collants à phéromones (pièges à ailettes de type I) et pièges phéromones de type seau (Universal Moth trap)] ont été évalués. Les pièges garnis de leurres de polyuréthane ont donné un meilleur rendement et produit moins de captures à fréquence zéro que les pièges à leurres à septums de caoutchouc. Il n’y avait pas de différence perceptible entre les taux de capture des divers pièges de polyuréthane en opération depuis 0–28 jours. Les pièges à ailettes ont atteint un point de saturation fonctionnel au moment des invasions des populations de livrées et capturé moins de livrées que des pièges Universal en dehors des périodes de foisonnement. La combinaison d’un piège non saturable comme le piège Universal et d’un leurre de polyuréthane semble constituer une technique bien appropriée à l’étude des populations de *M. disstria*.

[Traduit par la Rédaction]

Introduction

Populations of the forest tent caterpillar, *Malacosoma disstria* Hübner (Lepidoptera: Lasiocampidae), are well known for their periodic outbreaks and large

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fluctuations in abundance (Sippell 1957[2]). Outbreaks often result in reduced growth and dieback of the primary larval host of *M. disstria*, trembling aspen [*Populus tremuloides* Michx. (Salicaceae)] (Churchill *et al.* 1964; Pendrel 1991; Cooke 2001). An increase in the economic value of aspen began in the late 1980s (Bryson 1989), and aspen harvesting has undergone major economic development (Peterson and Peterson 1992). This shift in economic focus has been paralleled by a greater interest in insects and diseases affecting aspen. Predicting *M. disstria* outbreaks and monitoring their widely fluctuating populations for managing aspen harvest regimes has therefore become desirable. Similarly, research on *M. disstria* population dynamics has been primarily restricted to either high-density or collapsing populations (*e.g.*, Myers and Kukan 1995; Roland and Taylor 1997; for a complete bibliography see Otvos *et al.* 1998). Given the attention *M. disstria* has received in the scientific community, few empirical data are available on tent caterpillar ecology during the endemic population phase (but see Parry *et al.* 1997). One of the main impediments to studying endemic *M. disstria* populations has been the logistic difficulty of accurately determining *M. disstria* abundance. When abundance levels fall below the detection threshold of traditional estimating methods used at high population densities, such as egg mass counts (Shepherd and Brown 1971), *M. disstria* population size cannot be determined. Pheromone-trapping has the potential to precisely and accurately measure population densities over a range of *M. disstria* abundances, which can vary over several orders of magnitude.

The presence of a sex pheromone for *M. disstria* was first reported by Struble (1970), although the specific pheromone components were unknown. Ten years later, Chisholm *et al.* (1980) found that a straight-chained 12-carbon aldehyde, (*Z,E*)-5,7-dodecadienal, and the corresponding alcohol were two principal components. Although all four isomers of the C_{12}-5,7-aldehydes, alcohols, and acetates were evaluated using electroanntenogram and behavioural bioassays, only the (*Z,E*)-aldehyde and alcohol were field tested (presumably because these elicited the greatest response). Furthermore, Chisholm *et al.* (1980) found that male antennal stimulation occurred in response to a range of monounsaturated C_{12}-aldehydes, although these compounds did not attract males in the field. The (*Z,Z*)-aldehyde isomer and monounsaturated *Z*-7-dodecanal increase the attractiveness of (*Z,E*)-5,7-aldehyde in the field (unpublished results cited in Chisholm *et al.* 1982; Schmidt *et al.* 2003), although it was previously shown that these *Z,Z*- and *Z*-aldehydes were not effective field lures when used alone (Chisholm *et al.* 1980).

The variables tested here, with the goal of developing an effective pheromone trapping system for estimating *M. disstria* populations, include pheromone dispenser (lure) type, lure age, and trap design. Specifically, field experiments were conducted to (*i*) compare the performance of rubber septa to polyurethane lures, (*ii*) determine the longevity of lures in the field, and (*iii*) compare the performance of sticky-type to high-capacity pheromone traps.

Materials and methods

Study sites

Field experiments were carried out at three sites, which were representative of outbreak, moderate, and nonoutbreak *M. disstria* densities, respectively, between 1998 and 2000. Sites corresponding to the varying population levels were located near Prince George, British Columbia (53°50′N, 122°55′W), Redwater, Alberta (53°55′N,

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[2] WL Sippell. 1957. A study of the forest tent caterpillar and its parasite complex in Ontario. *Agriculture Canada Great Lakes Forest Research Centre Ontario Region Unpublished Report* 1957(12).

112°57′W), and Cooking Lake, Alberta (53°28′N, 112°47′W), respectively. The Prince George site consisted of aspen-dominated mixed-wood forest within the sub-boreal spruce biogeoclimatic zone (Meidinger and Pojar 1991). Additional canopy species include white spruce [*Picea glauca* (Moench) Voss (Pinaceae)], paper birch [*Betula papyrifera* Marsh. (Betulaceae)], and balsam poplar [*Populus balsamifera* L. (Salicaceae)]. The Cooking Lake site has a canopy composition similar to that of the Prince George site. The terrain at the Redwater Natural Area consists of stabilized sand dunes, and is characterized by a composite of upland and wetland plant communities. Open jack pine, *Pinus banksiana* Lamb. (Pinaceae), forest is interspersed with stands of trembling aspen, paper birch, and black spruce [*Picea mariana* (Mill.) BSP (Pinaceae)].

Lure type

The field performance of two lure types, the commonly used rubber septum (Daterman 1982) and a urethane lure (Flex Lure, Phero Tech Inc, Delta, British Columbia), was evaluated. Both lure types were obtained from Phero Tech Inc. The urethane lure used in this study measured 3.2 mm in diameter by 25.0 mm in length and consisted of a pheromone–polyurethane mix injected into plastic tubing. Manufacturing methods are detailed in the Canadian patent # 2,218,157 and the US patent # 5,750,129. The active ingredient used in these lures was a two-component aldehyde blend, consisting of (*Z*,*E*)-5,7-dodecadienal:(*Z*,*Z*)-5,7-dodecadienal (100:1) (Palaniswamy *et al.* 1983; hereinafter referred to as *Z*5*E*7-12Al and *Z*5*Z*7-12Al, respectively), at concentrations of 67 µg per lure (Schmidt *et al.* 2003). The isomer distribution of the *Z*5*E*7-12Al:*Z*5*Z*7-12Al blend consisted of 67.2% *Z*,*E*, 1.6% *Z*,*Z*, and 21.2% *E*,*E*; however, the *E*,*E* isomer of dodecadienal is not known to elicit any response in males (Chisholm *et al.* 1982), so its presence in the pheromone blend is not further addressed here. Lures were placed inside wing traps (Phero Tech Inc), which are constructed of a polycoated cardboard bottom tray with a 15 × 13 cm sticky surface. This piece fits tightly to a 23 × 28 cm cover from which the lure is suspended. Traps were deployed at outbreak (Prince George) and endemic (Cooking Lake) population densities, in a randomized block configuration, consisting of three treatments per block: the two lure types discussed here and an additional pheromone-type treatment discussed elsewhere (Schmidt *et al.* 2003). Traps were spaced at 50 m and were suspended from tree branches between 1.5 and 2 m above ground level. Traps were set out in early July 1998 and were recovered during the last week of August. Voucher specimens of *M. disstria* are located in the University of Alberta Strickland Entomology Museum, Edmonton, Alberta, Canada.

Mean trap catch between treatments was compared separately for the outbreak and endemic populations. Because log-transformation failed to adequately normalize the distribution of the count data, nonparametric methods were used to compare treatments (Zar 1999): mean trap catches for the two trap types were compared using Wilcoxon's paired-sample test for data from outbreak populations and the Mann–Whitney test for the endemic population data, as pairing was not recorded for the latter sites. To test whether or not the frequency of zero catches was equal between traps baited with rubber septa and urethane lures, a χ^2-test statistic was calculated based on a 2 × 2 contingency table with one fixed margin (Zar 1999).

Lure longevity

Longevity of the urethane lure was tested under field conditions, with the two-component aldehyde described above. Lures loaded with 95 µg of pheromone were tested using the Universal Moth Trap (Uni-trap), which is a nonsaturating, plastic bucket-type trap. Because trap colour is known to affect trap performance (Hendricks and Calcote 1991, and references therein), green trap components were consistently selected for all trials. A 2.5 × 4.5 cm piece of Hercon® Vaportape II (Phero Tech Inc) was placed inside the traps as a killing agent. Fourteen traps were placed out at 7-day intervals at the Redwater study site, with the first replicates set out on 26 June 2000. This resulted in field-aged lures of 0, 7, 14, 21, and 28 days by late July. The few moths that were caught in the traps prior to the deployment of unaged (0 day) traps were removed. Traps were placed within 5 m of the forest edge, at 100-m intervals along Township Road 572 and Range Road 205, in and adjacent to the Redwater Natural Area. The five age treatments were randomized within 14 blocks.

To compare lure longevity to the average phenology of *M. disstria* moths in Alberta, historical records of collection dates were compiled from pinned moth specimens. Label data were recorded from specimens in the University of Alberta Strickland Museum and the Northern Forestry Centre (Canadian Forest Service, Edmonton, Alberta). Pinned moths reared from collections of larvae were not included.

Trap catch among lure ages was compared using a nonparametric analysis of variance (Zar 1999). Because the overall trap catch was low (mean = 1.10 moths per trap, SE = 0.16) and five treatments were being compared simultaneously, we also compared 0- and 28-day-old lures separately. This provided a statistically more powerful means by which to test the effect of lure age on trap catch.

Trap design

Two pheromone-trap designs widely used for monitoring Lepidoptera pests were evaluated for trapping efficacy, namely the Wing Trap I and the Uni-trap (described above). Hercon® Vaportape II was used as a killing agent in the Uni-traps. The trial comparing wing-trap to Uni-trap performance consisted of 14 replicates of each trap type, alternately placed at 100-m intervals, and suspended 1.5–2 m above ground level. Traps were placed in the field on 25 June 2000 and catches were recorded 60 days later. The Mann–Whitney *U* test (Zar 1999) was used for statistical comparisons of trap catches. Proportion of zero catches and nonzero catches between trap types were compared using a χ^2-test statistic based on a 2 × 2 contingency table with one fixed margin (Zar 1999). Wing-trap capacity was estimated visually from saturated trap samples obtained from a separate study that was carried out at the outbreak site (Prince George) in 1998 (Schmidt *et al.* 2003).

Results

Lure type

At endemic *M. disstria* densities, approximately 10 times more males were captured in wing traps baited with the urethane lure than in wing traps using a rubber septum (Fig. 1). Rubber septum trap samples also had a higher frequency of zero catches than did the urethane lure traps ($\chi_1^2 = 9.88$, $P < 0.005$; Table 1). In outbreak populations at Prince George, there was no significant difference in trap catch between wing traps baited with the urethane lure and those baited with rubber septa (Fig. 1). This lack of a lure-type effect at high densities was probably due to the saturation of the wing trap's sticky surface by *M. disstria* moths (see Trap design below). All traps caught at least one moth at outbreak densities, precluding comparison of zero-catch frequencies.

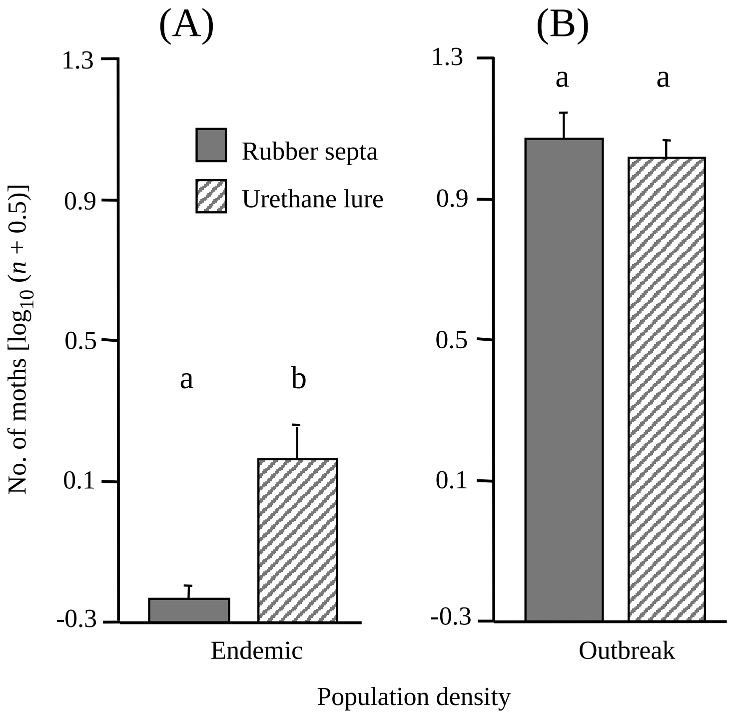

FIGURE 1. Catches (mean + SE) in wing traps as a function of lure type at endemic (A) and outbreak (B) *Malacosoma disstria* densities. For each lure type, different letters indicate differences (A, Mann–Whitney test, $P < 0.001$; B, Wilcoxon's paired-sample test, $P > 0.05$) in catch.

TABLE 1. Frequency of zero catches using different lure and trap types at endemic *Malacosoma disstria* densities.

	Lure type		Trap type	
Trap catch	Rubber septum	Urethane	Uni-trap	Wing trap
0	18	7	4	6
>0	3	14	10	8
Total	21	21	14	14

Lure longevity

The number of moths captured did not differ among age treatments of the urethane lure (Kruskal–Wallis, $H_4 = 3.64$, $P = 0.46$; Fig. 2). Similarly, there was no difference in trap catch when comparing only the 0- to 28-day-old lures (Mann–Whitney, $U_1 = 84$, $P > 0.05$). Capture dates of moths from historical records ranged from 22 June to 21 August, with 91% of the records occurring between 1 July and 10 August (Fig. 3). The peak in adult flight activity from historical records occurs between 11 and 20 July.

Trap design

At endemic densities, the Uni-trap caught about twice as many moths as the wing trap ($T_{14} = 0$, $P < 0.001$; Fig. 4). The proportion of traps with zero catches was higher

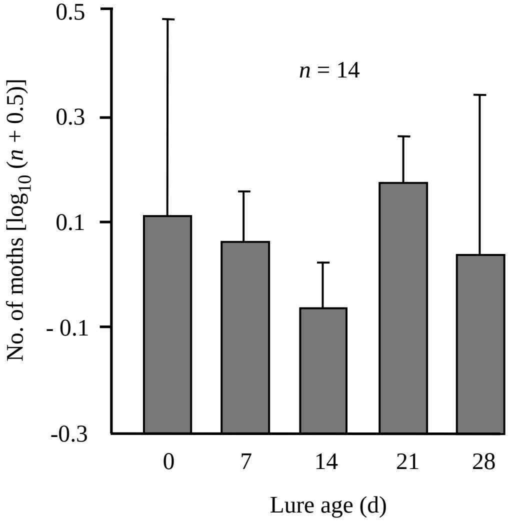

FIGURE 2. Number (mean + SE) of *Malacosoma disstria* moths captured as a function of lure age when traps were deployed on the same date. Trap catch is not different between lure age treatments (Kruskal–Wallis test, *P* > 0.05).

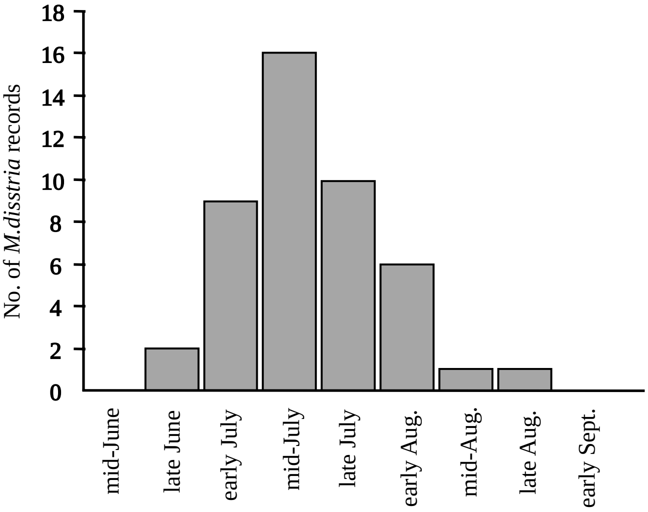

FIGURE 3. Seasonal distribution of historical *Malacosoma disstria* adult collection records for Alberta, 1915–2000. Early, 1st–10th day of the month; mid-, 11–20th day of the month; late, 21st – last day of the month.

for the wing traps than for the Uni-traps, but not significantly so ($\chi^2_1 = 0.16$, $P = 0.50$; Table 1).

Wing traps set out at the outbreak site became completely covered with moths, wing scales, and hairs. Wing-trap capacity was visually estimated to be between 20 and 25 moths, based on the absence of the functional sticky surface area remaining. Functional saturation of traps masked the effects of the lure-type treatment at high densities (Fig. 1).

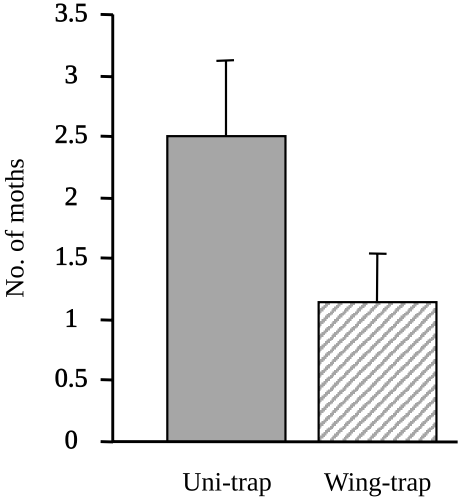

FIGURE 4. Number (mean + SE) of *Malacosoma disstria* moths captured using the Uni-trap and wing trap at endemic population levels. Trap catch is different (Mann–Whitney test, *P* < 0.001).

Discussion

Many published studies have measured pheromone-trap effectiveness by the number of insects captured (*e.g.*, Lewis and Macauley 1976; Vincent *et al.* 1993; Lopez 1998). When traps are used to estimate insect density, however, the important criterion is not necessarily the number of insects caught, but how accurate the density estimates are. To achieve accurate population estimates, traps should (*i*) be able to capture insects at the lowest population density to resolve among differing but low densities, (*ii*) be consistently efficient from year to year, (*iii*) have the capability of holding trapped insects without becoming saturated, and (*iv*) exhibit low catch variability (all else being equal). In an effort to develop an effective pheromone trapping system for the study of *M. disstria* populations, lure type, trap design, and lure age were evaluated using a synthetic pheromone [5*Z*7*E*-12Al:5*Z*7*Z*-12Al (100:1)] (Schmidt *et al.* 2003).

At endemic *M. disstria* densities, traps baited with the urethane lure caught more moths and had fewer zero catches than traps baited with rubber septa. The difference in capture rates owing to lure type was not evident in outbreak populations, likely attributable to the functional saturation of the trap's sticky surface by moths, which would have masked any treatment effects on trap catch. Differences in catch rates between the two lures can be explained by their respective pheromone release rates over time. The release rate of the rubber septum decreases exponentially over time (Butler and McDonough 1981), and its attractiveness to males therefore decreases rapidly. Polyurethane lures, which exhibit a gradual decrease in release rate much like polyethylene lures (McDonough *et al.* 1992), would maintain their attractiveness for a longer time period. The half-life of active ingredients on rubber septa depends on the volatility of the compounds involved (Butler and McDonough 1981). The half-lives of 12-carbon diunsaturated aldehydes on rubber septa, such as those used in this study, are not known. However, Heath *et al.* (1986) reported half-lives of about 43 days for monounsaturated and saturated aldehydes, including that of (*Z*)-9-tetradecanal which is a monounsaturated 14-carbon aldehyde. Because both unsaturation and decreasing carbon chain length exponentially diminish the half-life of aldehydes (Heath *et al.* 1986), a 12-carbon diunsaturated aldehyde would be expected to have a half-life which is substantially shorter than that of (*Z*)-9-tetradecanal. Assuming that the adult flight period spans approximately 30 days in a given year, and given that traps are deployed prior to the onset of the flight period, rubber septa become unattractive to males before the end of adult activity. Trap catch resulting from the use of rubber septa may therefore lead to inconsistent population estimates.

Field-aging urethane lures did not affect trap catch. Lures provided a constant catch rate over a period of 28 days, suggesting a relatively constant release rate over time. Urethane pheromone dispensers should then also provide uniform year-to-year trapping efficiency because the date of deployment, relative to the phenology of moth emergence, is not as crucial.

There is some evidence to suggest that sticky traps have higher capture rates at low target-insect densities than nonsaturating traps (Elkinton and Childs 1983; Angerilli and McLean 1984). In this study, the sticky wing trap proved to be less suitable for trapping males than the high-capacity Uni-trap at both high and low *M. disstria* population levels. At epidemic levels, wing traps become saturated and are ineffective. Efficiency of sticky traps also decreases prior to the saturating point, as moths accumulate on the sticky surface (Daterman 1982). Wing-trap saturation occurs at approximately 20 *M. disstria* moths per trap or 0.1 moths per cm^2 of sticky surface. Shepherd *et al.* (1985) found that delta-type sticky traps became saturated with Douglas-fir tussock moths [*Orgyia pseudotsugata* (McDunnough)] at approximately 0.06 moths per cm^2. Given that the Douglas-fir tussock moth has a slightly larger wing area (Ferguson 1978) than *M. disstria*, the trap saturation point is comparable between these two species.

At endemic *M. disstria* population levels, the Uni-trap had a greater ability to resolve *M. disstria* abundances than wing traps. The higher counts (and fewer zero counts) suggest that Uni-traps are more efficient at capturing moths, *i.e.*, either more moths are attracted to the trap owing to pheromone plume characteristics and (or) fewer moths escape the trap. The open, circular design of the Uni-trap allows omni-directional dispersal of the pheromone plume, whereas the wing trap, which is open to air movement from only two ends, would produce a more eccentric plume. At high *M. disstria* density, the Uni-trap should also provide more accurate *M. disstria* population estimates than sticky traps because the functional saturation point is much higher. Given the results of the Uni-trap/urethane lure used in conjunction with 5*Z*7*E*-12Al:5*Z*7*Z*-12Al:7*Z*-12Al (100:1:10) as an active ingredient (Schmidt *et al.* 2003), this system should provide the basis for an effective *M. disstria* monitoring protocol.

Further work should be directed towards developing the trapping system presented here as a predictive tool of *M. disstria* outbreaks. Attempts should be made to correlate trap catch to larval population density (Shepherd *et al.* 1985) to establish trap-catch levels indicative of incipient outbreaks. Depending on the desired precision of *M. disstria* population estimates, the number of trap replicates per site, trap spacing, and trap configuration may also be worth investigating, because these factors influence the precision of population estimates (Shepherd *et al.* 1985). It would also be desirable to determine the effects of trap colour on trap catch and if there are any detrimental (or positive) effects of the insecticidal strips in the traps. Each of these factors affect efficiency of Uni-traps for trapping other Lepidoptera (Lindgren *et al.* 1984; Sanders 1986; Hendricks and Calcote 1991; Lopez 1998).

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