

# Defoliation in Perennial Plants: Predictable and Surprising Results in *Senna* spp.

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**Abstract:** When some plants are defoliated, they may suffer by reaching a smaller final size than if they had not been damaged. Other plants may compensate for damage, ending up the same size as if they had not been damaged. Still, others may overcompensate, ending up larger after defoliation than if they had been spared from damage. We investigated the response of *Senna* species (Fabaceae) to defoliation, comparing two native and several ornamental congeners, all of which grow locally in southern Florida. Many *Senna* spp. bear foliar nectaries as nutritional resources for beneficial insects that may, in exchange, protect them from herbivores. We grew five species from seed and subjected them to three levels of defoliation for a period of several months to measure effects of leaf area removal on plant height, number of leaves, and number of extrafloral nectaries. Only three of five species displayed shorter plant heights with greater levels of damage. Two species produced fewer new leaves with moderate to severe defoliation. In only one species, the number of extrafloral nectaries decreased with defoliation, suggesting that while extrafloral nectar production may be an inducible defense in some species, producing more nectaries in response to damage does not occur in these *Senna* species.

**Keywords:** compensation; defense; defoliation; extrafloral; Fabaceae; foliar; induction; legume; nectaries



**Citation:** Koptur, S.; Primoli, A.S.; Pimienta, M.C. Defoliation in Perennial Plants: Predictable and Surprising Results in *Senna* spp. *Plants* **2023**, *12*, 587. <https://doi.org/10.3390/plants12030587>

Academic Editors: Paula Baptista and Livy Williams

Received: 30 December 2022

Revised: 26 January 2023

Accepted: 26 January 2023

Published: 29 January 2023



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## 1. Introduction

Plants are autotrophs, using the sun's energy and carbon dioxide to produce sugars and energy for their growth and structures. They are food for herbivores, a conduit for that energy from the sun to the next trophic level. Herbivores, primary consumers in most food webs, come in all shapes and sizes, and eat plants in various ways [1]. The most visible loss of tissues happens when parts are consumed, such as leaves, flowers, and fruits removed by animals.

What happens when plants are eaten? If entirely consumed, a plant will die, and if its biomass is greatly reduced but not enough energy was stored, the damage may also inflict mortality. If tissues are lost to herbivores, the amount of photosynthate produced is reduced, and plants may show reduced growth [2] or reproduce less [3,4]. Depending on the life history and habitat of the plant, the effects may be expressed the same, or the following, year [5–7]. Some damaged plants may regrow to the size of uneaten plants; compensation for herbivory [8,9] is facilitated by greater root/shoot ratios [10], storage organs [11,12], or by upregulation of the plant's physiological responses and growth [13,14]. Additionally, other plants may regrow even larger or reproduce more than uneaten plants, a phenomenon called over-compensation [15].

*Senna* species are perennial plants in the Fabaceae family, with life forms from herbs, shrubs, to small trees. They serve as host plants for sulphur butterflies (Pieridae), whose caterpillars may at times defoliate them severely [16,17]. In south Florida, two *Senna* species are native: *Senna mexicana* occurs in pine rocklands, and *S. ligustrina* occurs in wet prairie habitats. Both are used in native plant landscaping. With their bright green foliage

and yellow flowers, other exotic species are used in landscaping as well, including the candlestick plant (*S. alata*), the desert senna (*S. polyphylla*), and golden senna (*S. surattensis*). All species are used as host plants by butterflies in southern Florida [18].

Many *Senna* species (including those mentioned above) bear foliar nectaries [19] on their compound leaves [20], which serve to attract ants and other beneficial insects [21–24], though those insects may not always provide defense [25]. Studies on *S. mexicana* var. *chapmannii* have shown that nectar production is greater at night (as in many other species, e.g., [26]), older plants produce more nectar than younger plants [27], and nectaries are not present on seedlings. Nectar production is inducible, elevated in response to leaf damage [27], as has been found in other plants [28–34].

Extrafloral nectar provides effective biotic defense against herbivory in *S. mexicana*: when ants are excluded from plants, there are more caterpillars eating the leaves and flowers [17]. The presence of ants increases *Senna* plant reproductive fitness, but only in sunny habitats [35], as has been found in other plants bearing extrafloral nectaries [36]. The plants with ants grew larger, had bigger floral displays, attracted more pollinators, and set more fruit [37]. Studies with other plants have found that some respond to defoliation by producing more nectaries on leaves produced after damage [29,38–41].

We sought to compare the short-term responses of congeneric species of *Senna* (Fabaceae) to artificial defoliation. By subjecting individual seedlings to continuing levels of leaf loss over their development, we could see if and how defoliation affected their growth, production of new leaves, and the number of extrafloral nectaries on their foliage. Our questions were:

- (1) Will plants experiencing greater levels of defoliation grow less than those with less damage?
- (2) Will plants experiencing greater levels of defoliation produce fewer new leaves?
- (3) Will plants experiencing greater levels of defoliation produce more foliar nectaries?

The null hypotheses are that the amount of leaf damage will have no effect on *Senna* plant height, number of new leaves produced, or number of extrafloral nectaries. Alternatively, these variables may increase or decrease in comparison to the non-defoliated controls.

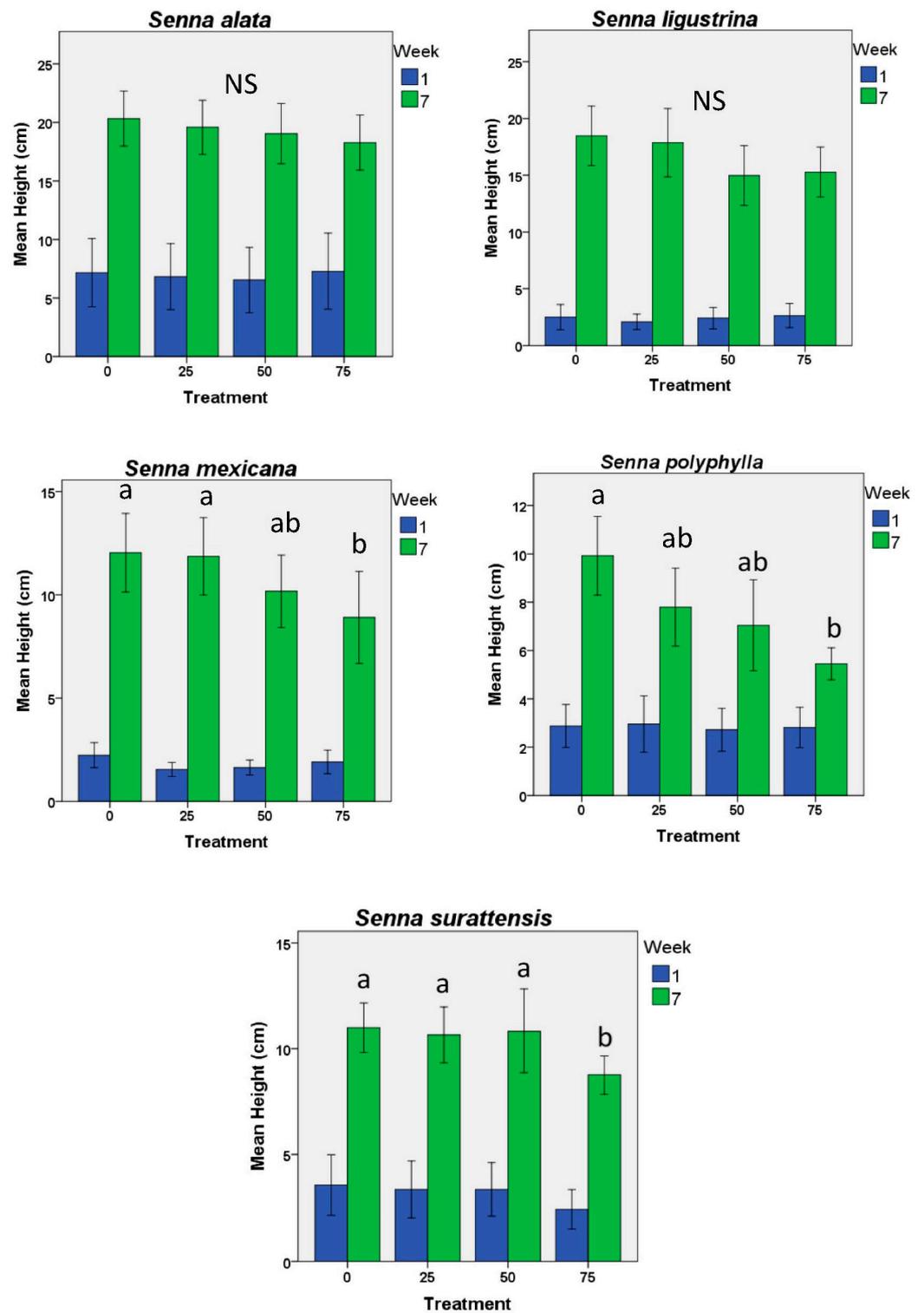
Our expectation was that *Senna* species might differ in their responses, related perhaps to their relative sizes. The same amount of damage on a smaller plant may have a greater impact than that amount on a larger plant. We predicted that larger *Senna* plants might compensate for defoliation and grow to sizes similar to undamaged plants. We also predicted they might produce more foliar nectaries on more heavily defoliated plants.

## 2. Results

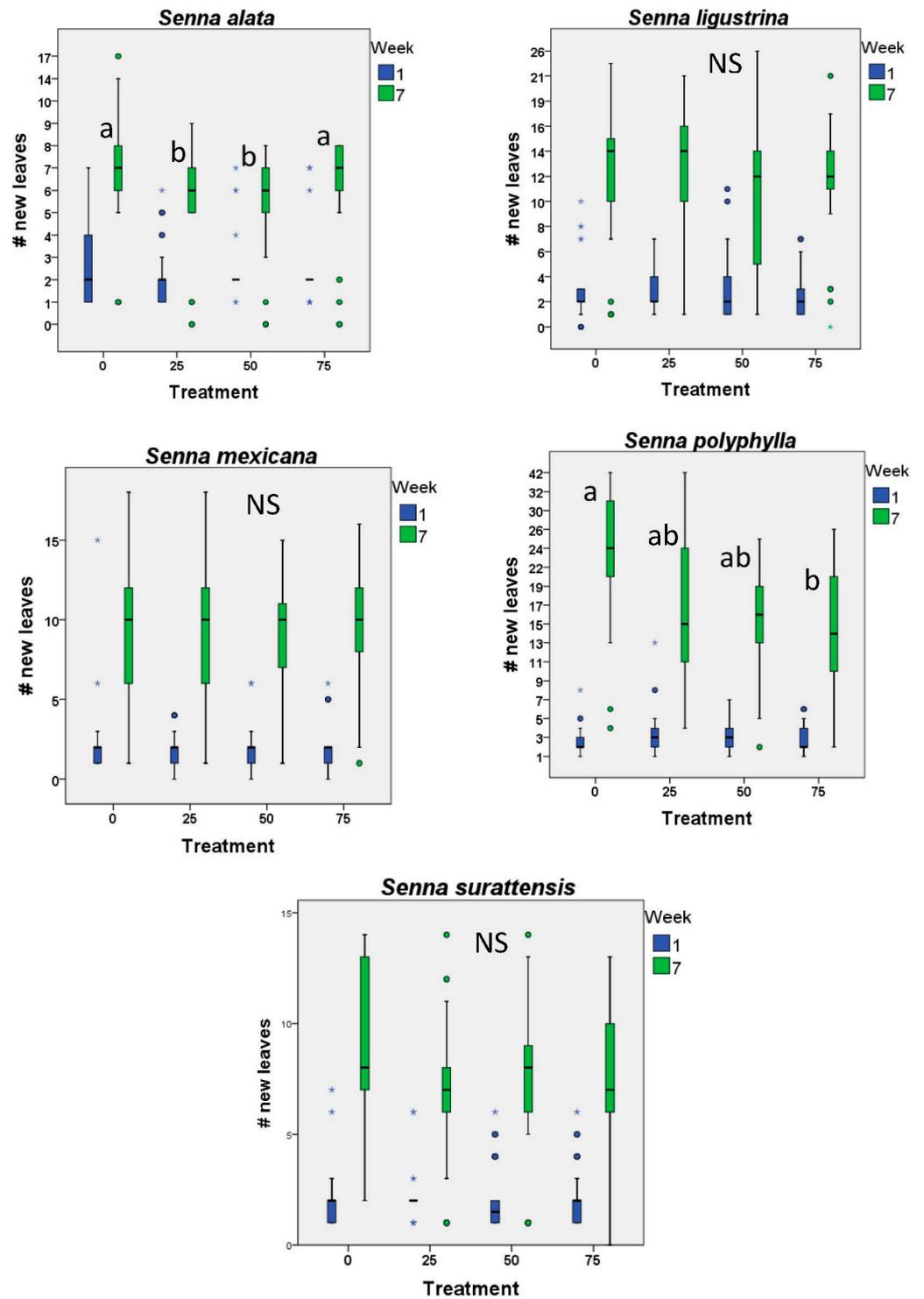
For three of the five species (*S. mexicana*, *polyphylla*, and *surattensis*), plants were shorter with higher levels of defoliation (Figure 1). The other two species (*S. ligustrina* and *S. alata*) showed no effects of defoliation on their final heights.

Only one species (*S. polyphylla*) produced fewer new leaves with higher levels of defoliation. Interestingly, *S. alata* produced fewer new leaves at intermediate levels of defoliation. All other species seemed to compensate for lost leaf area, producing the same number of new leaves as undamaged controls (Figure 2).

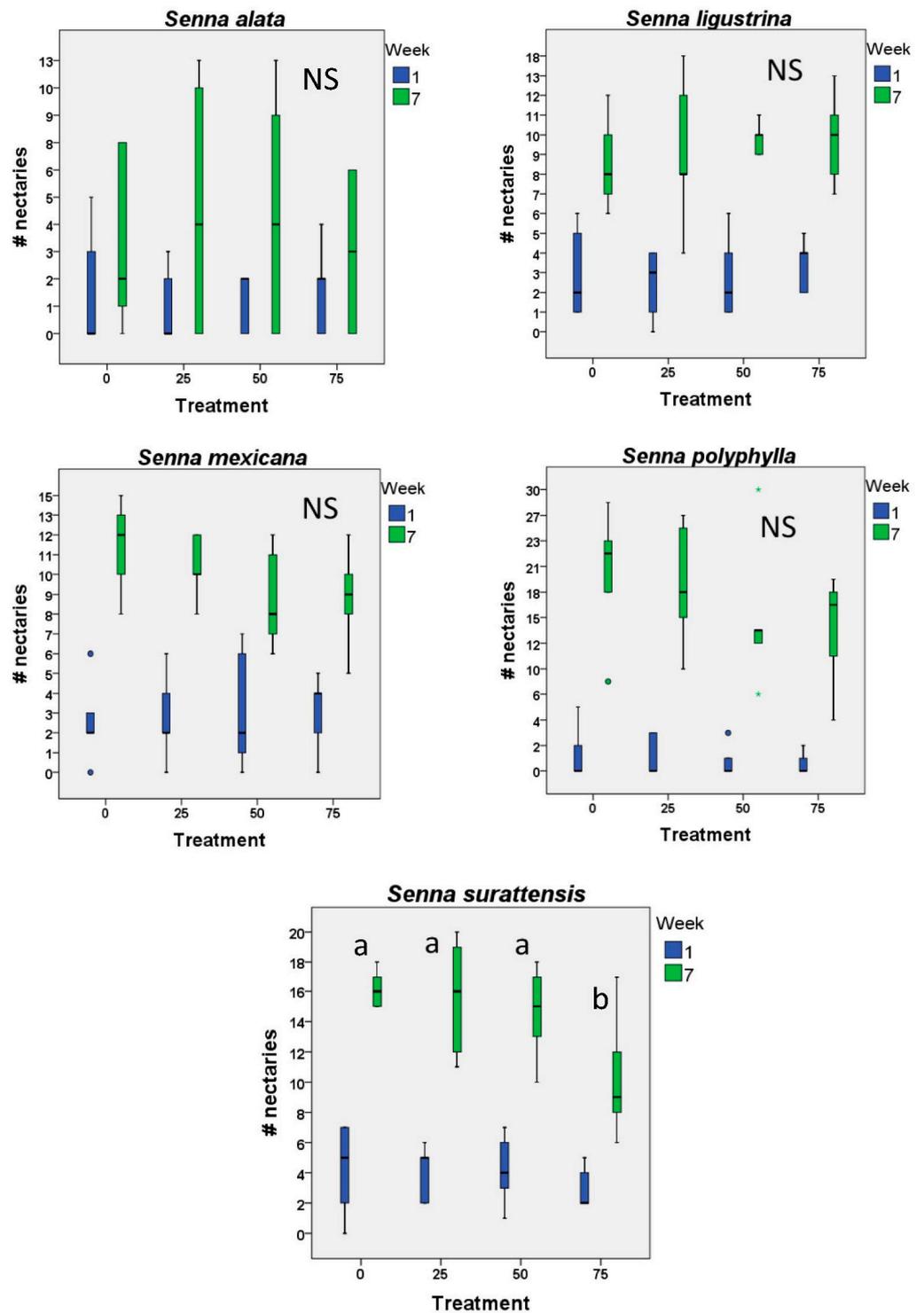
We have data for the number of nectaries from only one year, and just one species (*S. surattensis*) produced significantly fewer nectaries with higher levels of defoliation (Figure 3). Perhaps with a larger sample size, we might have seen a significant difference in other species that showed a similar trend (*S. mexicana* and *S. polyphylla*).



**Figure 1.** Heights—mean (+2 S.E.) beginning and final heights of five species of *Senna* subject to different levels of artificial defoliation over the first two months of life ( $n = 22$  plants each level and control). In no case were the initial heights different among the treatment groups. Small letters by bars indicate significant differences ( $p < 0.05$ ); bars with the same letters do not differ significantly from each other. NS indicates no significant differences found.



**Figure 2.** New leaves—bar and whisker plots for initial number of leaves and final number of new leaves produced on five species of *Senna* subject to different levels of artificial defoliation over the first two months of life ( $n = 22$  plants each level and control). In no case were the initial number of leaves different among the treatment groups. Small letters by bars indicate significant differences ( $p < 0.05$ ); bars with the same letters do not differ significantly from each other. NS indicates no significant differences found.



**Figure 3.** Extrafloral nectaries—bar and whisker plots for initial and final number of extrafloral nectaries on five species of *Senna* subject to different levels of artificial defoliation over the first two months of life ( $n = 12$  plants each level and control). In no case were the initial number of nectaries different among the treatment groups. Small letters by bars indicate significant differences ( $p < 0.05$ ); bars with the same letters do not differ significantly from each other. NS indicates no significant differences found.

### 3. Discussion

The three *Senna* species that showed decreased height with severe defoliation apparently compensated for mild and moderate defoliation. Our results demonstrate that *Senna* spp. are more resilient to defoliation than, for example, *Mimosa pigra* [42], which could only compensate with mild defoliation.

The species of *Senna* that produced fewer new leaves in response to higher levels of defoliation apparently had less ability to compensate for leaf area lost, perhaps due to having less storage in their non-photosynthetic parts. To better understand this possibility, the biomass root/shoot ratio of the species could be compared.

The only species that produced fewer extrafloral nectaries was *S. surattensis*, the one that bears multiple nectaries per leaf; all other species we studied have only one. Multiple nectaries may be a more labile trait and are a characteristic of other species that have been found to produce more nectaries with defoliation, such as *Mallotus japonicus* (Euphorbiaceae) [41], *Sapium sebiferum* (Euphorbiaceae) [29], *Prunus avium* (Rosaceae) [40], and *Vicia faba* (Fabaceae) [38,43]. However, the response of *S. surattensis* was to produce fewer, not more, foliar nectaries with higher levels of defoliation. Rather than the formation of nectaries being an inducible defense in *Senna*, it may be a feature that can be cut back as defoliation limits energy resources. It has been shown that greater extrafloral nectar production is induced with defoliation in *S. mexicana* [27], but in the present study, nectar quantity was not measured. In a future study, it will be worth investigating if this is a general response among *Senna* species.

A similar field experiment with *Qualea multiflora* in the Brazilian *cerrado* showed that higher levels of defoliation led to greater nectar production and greater ant attendance [44]. Plants with more and better nectar receive greater levels of defense, as demonstrated in another field experiment involving a single species of ant and its predation on termites on five different plant species [45], and greater amounts of extrafloral nectar have a direct positive effect on ant colony fitness [46].

Our results must be interpreted with some caveats in mind. With less than two months of growth, we cannot be certain that greater differences among treatments might not have emerged over time. Many other studies have followed plants over an entire growing season, or more. Furthermore, the timing of defoliation can have substantially different effects on subsequent growth and reproduction as found in *Sesbania* (Fabaceae) [4], as well as their survival, as seen in *Prosopis* (Fabaceae) [47], though in some plants it does not make a difference [44].

This study was performed on potted plants in a greenhouse, not in nature. As Agrawal [48] observed: “Resource limitation is only half of understanding trade-offs . . . the rest is community ecology”. Subtle differences in plant stature and leaf number may be more meaningful when a plant grows with neighbors of the same and other species [49], so that responses among individuals may be significant for those individuals even if the average response seen in isolated plants may not be.

Our defoliations were artificial, performed with scissors, not real herbivores; in some species, this has been shown to make a difference. Real herbivores had a greater effect on eucalyptus seedlings than did artificial defoliation [50]. Similar comparisons with *Mimosa pigra* (Fabaceae) showed no difference [42].

Some studies have found greater sensitivity to defoliation in non-native vs. native species [51], though we did not see this difference in the congeneric species in this study. While sulphur butterflies oviposit on all the *Senna* spp. we studied, there is no apparent preference for either native or non-native species (Koptur and Salas, unpublished data), despite the general findings that non-native species suffer greater defoliation than natives in a given habitat [52].

Our challenge now is to learn how different levels of defoliation affect the growth, competitive ability, and reproduction of these plants in nature. While the sulphur butterflies, *Phoebis* spp. (Pieridae), normally remove leaf material from *Senna* plants to levels of less than 25%, the sleepy orange butterfly (*Abaeis nicippe*, Pieridae) oviposit prolifically and the

caterpillars may defoliate plants to levels in excess of 80% [16]. Our greenhouse experiments and previous field experiments [17–19,35,37] have controlled for surroundings and many of the interactions naturally occurring plants experience. We hope these will enable us to better interpret the responses observed in nature.

## 4. Materials and Methods

### 4.1. Study Species

We investigated five species of *Senna* (Figure 4), two native to south Florida and three exotic species. The two native species are similar in general appearance of leaves and flowers, but the leaflets and foliar nectaries of *Senna ligustrina* (L.) H.S. (Irwin and Barnaby) are pointed, whereas those of *S. mexicana* var. *chapmannii* (Isely) H.S. (Irwin and Barnaby) are rounded. Naturally occurring in wetlands, *S. ligustrina* grows as an upright, multi-stemmed shrub reaching 2 m in height, whereas *S. mexicana* plants in pine rocklands are lower-growing (normally 1 m or less in height) and tend to sprawl laterally.

The three exotic species are quite different in appearance and habit. A big, robust shrub with large sprawling branches up to 2 or more meters tall, *Senna alata* (L.) Roxb. has very large leaves with glandular stipules [53,54], and perhaps glandular areas between leaflets as well, nectaries termed non-individualized nectaries by Marazzi et al. [55]. A more delicate shrub with small leaves and leaflets, *S. polyphylla* (Jacq.) (Irwin and Barnaby) has nectaries between the lowest pair of leaflets; they can grow up to be small trees up to 3 m in height. Commonly planted as a street tree in parking lots, on roadsides, and medians, *S. surattensis* (Burm. F.) (H.S. Irwin and Barnaby) has medium-sized leaves with rounded leaflets and nectaries between the lower pairs of leaflets.

### 4.2. Experimental Design

The experiment was conducted in spring of 2017 and spring of 2019 in the greenhouse facility of the Biology Department of Florida International University. Starting with bulk samples of seeds collected from at least four individuals of plants of five *Senna* species growing in south Florida, we scarified the seeds and soaked them overnight. Seeds were planted in standard greenhouse soil and germinated within two weeks of planting, growing to transplant size within a month.

Seedlings were potted individually in 4" pots and arranged in blocks in which all five species were each represented by four plants. One individual of each species was assigned to one of the following experimental treatments: no defoliation control, 25% defoliation, 50%, and 75% defoliation. These levels encompass the range of damage individual leaves and plants may experience in nature. On individual plants, each leaf was defoliated to the designated level, with new leaves defoliated each week. For this artificial defoliation, we used sharp scissors to simulate damage from externally feeding caterpillars.

After seven weeks, we measured plant height, the number of leaves, and number of nectaries (only in 2017) present on each individual plant. Data were combined for the two years to provide robust sample sizes. Twelve blocks were utilized in 2017, and ten in 2019, giving a total sample size of 22 plants in each treatment for each species. Plant height, a continuous variable, was compared among treatments with analysis of variance. The number of new leaves produced and the number of nectaries, count data, were compared with the non-parametric Kruskal-Wallis test.



**Figure 4.** *Senna* species and nectaries—(a) *Senna ligustrina* habit, (b) closeup of *S. ligustrina* nectary at base of leaf; (c) *S. mexicana* var. *chapmanii* habit, (d) closeup of *S. mexicana* nectary between lowest pair of leaflets; (e) *S. polyphylla* habit, (f) closeup of *S. polyphylla* nectary between lowest pair of leaflets. (g) *S. surattensis* habit, leaf with two foliar nectaries between basal leaflet pairs; (h) *S. surattensis* leaf with three nectaries, exuding nectar; (i) close-up of single nectary of *S. surattensis* between a pair of leaflets.

**Author Contributions:** Conceptualization, S.K., A.S.P., M.C.P.; methodology, S.K., A.S.P., and M.C.P.; formal analysis, S.K.; investigation, S.K., A.S.P., and M.C.P.; resources, S.K.; data curation, S.K.; writing—original draft prep S.K.; review and editing, A.S.P., M.C.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Approval and publication number granted.

**Data Availability Statement:** Data may be freely accessed from the FIU dataverse: <https://doi.org/10.34703/gzx1-9v95/VNZZJZ> (accessed on 1 December 2022).

**Acknowledgments:** We thank Scott Zona, curator, for supervision in the FIU greenhouse; students in Plant Ecology lab for their participation and assistance in conducting the experiment and collecting data; Brittany Harris, Blaire Kleiman, Ian Jones, and Scott Zona for constructive feedback on the manuscript. This is contribution #1530 from the Institute of Environment at Florida International University.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Crawley, M.J. *Herbivory. The Dynamics of Animal-Plant Interactions*; University of California Press: Berkeley, CA, USA, 1983; 437p.
2. Schupp, E.W. Azteca protection of *Cecropia*: Ant occupation benefits juvenile trees. *Oecol* **1986**, *70*, 379–385. [[CrossRef](#)] [[PubMed](#)]
3. Rockwood, L.L. The effect of defoliation on seed production in six Costa Rican tree species. *Ecology* **1973**, *54*, 1363–1369. [[CrossRef](#)]
4. Marshall, D.L.; Abrahamson, N.J.; Avritt, J.J.; Hall, P.M.; Medeiros, J.S.; Reynolds, J.; Shaner, M.G.M.; Simpson, H.L.; Trafton, A.N.; Tyler, A.P.; et al. Differences in Plastic Responses to Defoliation due to Variation in the Timing of Treatments for Two Species of *Sesbania* (Fabaceae). *Ann. Bot.* **2005**, *95*, 1049–1058. [[CrossRef](#)] [[PubMed](#)]
5. Archer, S.; Tieszen, L.L. Effects of simulated grazing on foliage and root production and biomass allocation in an arctic tundra sedge (*Eriophorum vaginatum*). *Oecologia* **1983**, *58*, 92–102. [[CrossRef](#)]
6. Rockwood, L.L.; Lobstein, M.B. The effects of experimental defoliation on reproduction in four species of herbaceous perennials from northern Virginia. *Castanea* **1994**, *59*, 41–50.
7. Reece, P.W.; Morris, J.W.; Schacht, W.H.; Koehler, A.E.; Volesky, J.D.; Moser, L.E. Prairie sandreed response to preceding-year defoliation and precipitation regime. *Great Plains Res.* **2007**, *17*, 215–224.
8. McNaughton, S.J. Compensatory plant growth as a response to herbivory. *Oikos* **1983**, *40*, 329–336. [[CrossRef](#)]
9. Klubertanz, T.H.; Pedigo, L.P.; Carlson, R.E. Soybean Physiology, Regrowth, and Senescence in Response to Defoliation. *Agron. J.* **1996**, *88*, 577–582. [[CrossRef](#)]
10. Barton, K.E.; Shiels, A.B. Additive and non-additive responses of seedlings to simulated herbivory and drought. *Biotropica* **2020**, *52*, 1217. [[CrossRef](#)]
11. Erb, M.; Lenk, C.; Degenhardt, J.; Turlings, T.C.J. The underestimated role of roots in defense against leaf attackers. *Trends Plant Sci.* **2009**, *14*, 653–659. [[CrossRef](#)]
12. Morris, C.D. Buried but unsafe—Defoliation depletes the underground storage organ (USO) of the mesic grassland geophyte, *Hypoxis hemerocallidea*. *S. Afr. J. Bot.* **2021**, *141*, 265–272. [[CrossRef](#)]
13. Hinman, E.D.; Fridley, J.D. Impacts of experimental defoliation on native and invasive saplings: Are native species more resilient to canopy disturbance? *Tree Physiol.* **2020**, *40*, 969–979. [[CrossRef](#)]
14. Meuriot, F.; Prud'homme, M.; Noiraud-Romy, N. Defoliation, wounding, and methyl jasmonate induce expression of the sucrose lateral transporter LpSUT1 in ryegrass (*Lolium perenne* L.). *Physiol. Plantarum.* **2022**, *174*, e13744. [[CrossRef](#)]
15. Agrawal, A.A. Overcompensation of plants in response to herbivory and the by-product benefits of mutualism. *Trends Plant Sci.* **2000**, *5*, 309–313. [[CrossRef](#)]
16. Fleet, R.R.; Young, B.L. Facultative Mutualism between Imported Fire Ants (*Solenopsis invicta*) and a Legume (*Senna occidentalis*). *Southwest. Nat.* **2000**, *45*, 289–298. [[CrossRef](#)]
17. Koptur, S.; Jones, I.M.; Pena, J.E. The Influence of Host Plant Extrafloral Nectaries on Multitrophic Interactions: An Experimental Investigation. *PLoS ONE* **2015**, *10*, e0138157. [[CrossRef](#)]
18. Koptur, S.; Jones, I.M.; Liu, H.; Diaz-Castelazo, C. Playing the System: The Impacts of Invasive Ants and Plants on Facultative Ant-Plant Interactions. In *Ant-Plant Interactions—Impacts of Humans on Terrestrial Ecosystems*; Oliveira, P.S., Koptur, S., Eds.; Cambridge University Press: Cambridge, UK, 2017; pp. 249–266.
19. Koptur, S. Extrafloral nectary-mediated interactions between insects and plants. In *Insect-Plant Interactions*; Bernays, E., Ed.; CRC Press: Boca Raton, FL, USA, 1992; Volume 4, pp. 81–129.
20. Marazzi, B.; Bronstein, J.L.; Koptur, S. The diversity, ecology and evolution of extrafloral nectaries: Current perspectives and future challenges. *Ann. Bot.* **2013**, *111*, 1243–1250. [[CrossRef](#)]
21. Bentley, B. Extrafloral nectaries and protection by pugnacious bodyguards. *Annu. Rev. Ecol. Syst.* **1977**, *88*, 407–427. [[CrossRef](#)]
22. Barton, A.M. Spatial variation in the effect of ants on an extrafloral nectary plant. *Ecology* **1986**, *67*, 495–504. [[CrossRef](#)]
23. Kelly, C.A. Extrafloral nectaries: Ants, herbivores and fecundity in *Cassia fasciculata*. *Oecol* **1986**, *69*, 600–605. [[CrossRef](#)]
24. Koptur, S. Nectar as fuel for plant protectors. In *Plant-Provided Food for Carnivorous Insects: Protective Mutualism and Its Applications*; Wackers, F.L., VanRijn, P.C.J., Bruin, J., Eds.; Cambridge University Press: New York, NY, USA, 2005; pp. 75–108.

25. Boecklen, W.J. The role of extrafloral nectaries in the herbivore defence of *Cassia fasciculata*. *Ecol. Entomol.* **1984**, *9*, 243–249. [[CrossRef](#)]
26. Lange, D.; Calixto, E.S.; Del-Claro, K. Variation in Extrafloral Nectary Productivity Influences the Ant Foraging. *PLoS ONE* **2017**, *12*, e0169492. [[CrossRef](#)] [[PubMed](#)]
27. Jones, I.M.; Koptur, S. Dynamic Extrafloral Nectar Production: The Timing of Leaf Damage Affects the Defensive Response in *Senna mexicana* var. *chapmanii* (Fabaceae). *Am. J. Bot.* **2015**, *102*, 58–66. [[CrossRef](#)] [[PubMed](#)]
28. Koptur, S. Is extrafloral nectar production an inducible defense? In *Evolutionary Ecology of Plants*; Bock, J., Linhart, Y., Eds.; Westview Press: Boulder, CO, USA, 1989; pp. 323–339.
29. Rogers, W.E.; Sieman, E.; Lankau, R.A. Damage Induced Production of Extrafloral Nectaries in Native and Invasive Seedlings of Chinese Tallow Tree (*Sapium sebiferum*). *Am. Midl. Nat.* **2003**, *149*, 413–417. [[CrossRef](#)]
30. Heil, M. Induction of two indirect defences benefits Lima bean (*Phaseolus lunatus*, Fabaceae) in nature. *J. Ecol.* **2004**, *92*, 527–536. [[CrossRef](#)]
31. Heil, M. Indirect defence via tritrophic interactions. *New Phytol.* **2008**, *178*, 41–61. [[CrossRef](#)]
32. Hernandez-Cumplido, J.; Forter, B.; Moreira, X.; Heil, M.; Benrey, B. Induced Floral and Extrafloral Nectar Production Affect Ant-pollinator Interactions and Plant Fitness. *Biotropica* **2016**, *48*, 342–348. [[CrossRef](#)]
33. Yamawo, A.; Suzuki, N. Induction and relaxation of extrafloral nectaries in response to simulated herbivory in young *Mallotus japonicus* plants. *J. Plant Res.* **2018**, *131*, 255–260. [[CrossRef](#)]
34. Chinarelli, H.D.; Nogueira, A.; Leal, L.C. Extrafloral nectar production induced by simulated herbivory does not improve ant bodyguard attendance and ultimately plant defence. *Biol. J. Linn. Soc.* **2021**, *135*, 429–446. [[CrossRef](#)]
35. Jones, I.M.; Koptur, S.; Gallegos, H.R.; Tardanico, J.P.; Trainer, P.A.; Peña, J. Changing light conditions in pine rockland habitats affect the intensity and outcome of ant-plant interactions. *Biotropica* **2017**, *49*, 83–91. [[CrossRef](#)]
36. Kersch, M.F.; Fonseca, C.R. Abiotic factors and the conditional outcome of an ant-plant mutualism. *Ecology* **2005**, *86*, 2117–2126. [[CrossRef](#)]
37. Jones, I.M.; Koptur, S.; Pena, J.E. Exploring whether and how ants (Hymenoptera: Formicidae) affect reproductive fitness in *Senna mexicana* var. *chapmanii* (Fabaceae). *Fla. Entomol.* **2017**, *100*, 539–545. [[CrossRef](#)]
38. Mondor, E.B.; Addicott, J.F. Conspicuous extra-floral nectaries are inducible in *Vicia faba*. *Ecol. Lett.* **2003**, *6*, 495–497. [[CrossRef](#)]
39. Mondor, E.B.; Tremblay, M.N.; Messing, R.H. Extrafloral nectary phenotypic plasticity is damage- and resource-dependent in *Vicia faba*. *Biol. Lett.* **2006**, *2*, 583–585. [[CrossRef](#)]
40. Pulice, C.E.; Packer, A.A. Simulated herbivory induces extrafloral nectary production in *Prunus avium*. *Funct. Ecol.* **2008**, *22*, 801–807. [[CrossRef](#)]
41. Yamawo, A.; Suzuki, N.; Tagawa, J. Extrafloral nectary-bearing plant *Mallotus japonicus* uses different types of extrafloral nectaries to establish effective defense by ants. *J. Plant Res.* **2019**, *132*, 499–507. [[CrossRef](#)]
42. Wirf, L.A. The effect of manual defoliation and *Macaria pallidata* (Geometridae) herbivory on *Mimosa pigra*: Implications for biological control. *Biol. Control* **2006**, *37*, 346–353. [[CrossRef](#)]
43. Mondor, E.B.; Keiser, C.N.; Pendarvis, D.E.; Vaughn, M.N. Broad bean cultivars increase extrafloral nectary numbers, but not extrafloral nectar, in response to leaf damage. *Open J. Ecol.* **2013**, *3*, 59–65. [[CrossRef](#)]
44. Calixto, E.S.; Lange, D.; Bronstein, J.; Torezan-Silingardi, H.M.; Del-Claro, K. Optimal Defense Theory in an ant-plant mutualism: Extrafloral nectar as an induced defence is maximized in the most valuable plant structures. *J. Ecol.* **2021**, *109*, 167–178. [[CrossRef](#)]
45. Calixto, E.S.; Lange, D.; Moreira, X.; Del-Claro, K. Plant species specificity of ant-plant mutualistic interactions: Differential predation of termites by *Camponotus crassus* on five species of extrafloral nectaries plants. *Biotropica* **2021**, *53*, 1406–1414. [[CrossRef](#)]
46. Calixto, E.S.; Lange, D.; Del-Claro, K. Net benefits of a mutualism: Influence of the quality of extrafloral nectar on the colony fitness of a mutualistic ant. *Biotropica* **2021**, *53*, 846–856. [[CrossRef](#)]
47. Weltzin, J.F.; Archer, S.R.; Heitschmidt, R.K. Defoliation and woody plant (*Prosopis glandulosa*) seedling regeneration: Potential vs realized herbivory tolerance. *Plant Ecol.* **1998**, *138*, 127–135. [[CrossRef](#)]
48. Agrawal, A.A. A scale-dependent framework for trade-offs, syndromes, and specialization in organismal biology. *Ecology* **2020**, *101*, e02924. [[CrossRef](#)] [[PubMed](#)]
49. Archer, S.; Detling, J.K. The Effects of Defoliation and Competition on Regrowth of Tillers of Two North American Mixed-Grass Prairie Graminoids. *Oikos* **1984**, *43*, 351–357. [[CrossRef](#)]
50. Quentin, A.G.; Pinkard, E.A.; Beadle, C.L.; Wardlaw, T.J.; O’Grady, A.P.; Paterson, S.; Mohammed, C.L. Do artificial and natural defoliation have similar effects on physiology of *Eucalyptus globulus* Labill. seedlings? *Ann. For. Sci.* **2010**, *67*, 203. [[CrossRef](#)]
51. Rakotonjoely, H.; Ramamonjisoa, N. Seedlings of the Invasive Strawberry Guava *Psidium cattleianum* Were More Sensitive to Defoliation Than the Closely Related Malagasy Native *Eugenia goviala* in a Simulated Herbivory Experiment. *Trop. Conserv. Sci.* **2020**, *13*, 1940082920961230. [[CrossRef](#)]
52. Agrawal, A.A.; Kotanen, P.M. Herbivores and the success of exotic plants: A phylogenetically controlled experiment. *Ecol. Lett.* **2003**, *6*, 712–715. [[CrossRef](#)]
53. Veeraragavan, S.; Ramamoorthy, D. Studies On Micro-Morphological Characteristics Of Extra Floral Nectar -Secreting Glandular Structures In *Cassia alata* Linn. *Int. J. Recent Sci. Res.* **2015**, *6*, 5759–5763.

54. Veeraragavan, S.; Ramamoorthy, D. SEM based anatomical studies in stipular extra floral nectary tissues in *Cassia alata* Linn. *Int. J. Curr. Res.* **2016**, *8*, 25955–25960.
55. Marazzi, B.; Conti, E.; Sanderson, M.J.; McMahon, M.M.; Bronstein, J.L. Diversity and evolution of a trait mediating ant-plant interactions: Insights from extrafloral nectaries in *Senna* (Leguminosae). *Ann. Bot.* **2013**, *111*, 1263–1275. [[CrossRef](#)]

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