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Cuban brown snail, *Zachrysia provisoria* (Gastropoda): Damage potential and control

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ABSTRACT

The snail *Zachrysia provisoria* (Pfeiffer) is poorly known in Florida, USA, where it predominately is viewed as a pest of ornamental plants. I evaluated its host plant relationships, foliage consumption potential, and susceptibility to several molluscicides. Many of the potential hosts, especially common ornamental plants that are planted densely as ground cover and might be expected to provide a favorable environment for snails, are not suitable for growth of young snails. Older snails, though displaying some ability to feed and damage hosts unsuitable for growth of young snails, displayed similar patterns of acceptance and growth. Several weeds were favorable for growth, suggesting that untended environments could lead to snail problems in adjacent ornamental plantings. The effect of plant condition (age) on snail feeding preference was assessed by measuring leaf consumption by snails presented simultaneously with young (green, located apically) and senescent (yellowing or yellow, located basally) leaves of a single plant species. From preferred host plants, snails chose young leaf tissue, but from less preferred plants they consumed senescent tissue. Foliage consumption potential was assessed using romaine lettuce at two constant temperatures, 24 and 32 °C. Foliage consumption increased with age (wet weight) at both 24 and 32 °C; however, the rate of consumption was higher at the lower temperature. At 24 °C, mean peak consumption was about 40 cm^2 of leaf area or 12 g wet weight/day. At the less favorable high temperature of 32 °C, mean peak consumption was reduced by about 50%, to a mean of only 20 cm^2 or 6 g wet weight/day. Relative consumption rate (cm^2 or g foliage/g snail) diminished with age (wet weight) of the snails. Several molluscicide-containing baits were assessed. Metaldehyde-based baits induced mortality most quickly, followed by iron-based baits. A boric acid-based bait was slowest, requiring 12 days for the induction of significant levels of mortality. All baits significantly suppressed feeding, however, sometimes even in the absence of mortality.

1. Introduction

Zachrysia provisoria (Pfeiffer, 1858) (Family Pleurodontidae [Camaenidae]) was originally described from Cuba, but now occurs on many islands in the Caribbean region as well as Florida (USA), Guatemala, and Costa Rica (Robinson and Fields, 2004). Pilsbry (1928) provides some descriptive information on this species and other members of the genus. Besides Pilsbry's brief observations noting the occurrence of this species mostly in humid forests, there is little scientific literature beyond his brief taxonomic treatment, some international distribution records, and some rearing studies (Capinera, 2012).

Z. provisoria was introduced deliberately into the Miami, Florida area in the early 1900s as a potential food source (Auffenberg and Stange, 1993), but since then has become the major snail pest of landscape plants in southern areas of the Florida peninsula (Pilsbry, 1939; Auffenberg and Stange, 1993), damaging flower and ornamental foliage plants. Some snails have become significant factors in interstate and international commerce, as they may cause economic or aesthetic damage when introduced into new areas. Thus, it is a quarantine problem. *Zachrysia* is of particular concern because they can be numerous in regions of Florida where ornamental plant production is an important industry, and will dig into the soil during the daylight hours, making detection difficult and inadvertent transport of the snails along with container-grown plants quite possible. Because it is a poorly known species, studies were conducted to assess damage potential and control.

2. Materials and methods

2.1. Host plants and foliage consumption

Because the plant hosts suitable for growth of immature *Z. provisoria* are unknown, I assessed the suitability of several plants

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(12 cultivated plants, 3 native uncultivated plants, 9 weeds, and two 5-plant mixtures) for young (about 50 mg wet weight) snail development and growth by providing them with potential natural diets. Young unfed snails ($n = 14$ per diet, 1–2 d old) were confined individually in 250 ml covered plastic containers with one of the aforementioned diets. Thus, I used 364 snails for the 26 diet treatments. These young snails were used only for these suitability studies, then destroyed. The snails were weighed weekly with a Mettler Toledo A104 analytical balance. Romaine lettuce, *Lactuca sativa* var. *longifolia* (Asteraceae) was used as a standard (control) because these snails, as well as most terrestrial plant-feeding molluscs, accept it readily. About 1 g (wet weight) of foliage was provided to each snail, with plant material monitored every 2–3 d and replaced as needed to ensure freshness. Also provided in each container was about 30 g of moistened soil to maintain high humidity in the containers and to serve as a source of dietary calcium. The snail culture was conducted in a room maintained at 26 °C and 14 h photoperiod. Snail wet weight was measured weekly for 5 weeks, although for some unacceptable diets, considerable mortality (≥50%) had occurred before this time, so data tabulation was terminated. Mean wet weight (SE) was calculated and plotted to determine trends in wet weight gain on the various diets. Many of the snails in these studies died, but survivors were also destroyed and not used in other host selection studies.

Plants evaluated for suitability to support young snail growth, in addition to romaine lettuce, included several ornamental plants: St. Augustinegrass, *Stenotaphrum secundatumcoleus* (Poaceae); coleus, *Solenostemon* sp. (Lamiaceae); peace lily, *Spathiphyllum* sp. (Araceae); lubbersiana, *Ctenanthe lubbersiana* (Marantaceae); purple queen, *Tradescantia pallida* (Commelinaceae); cutleaf philodendron, *Philodendron monstera* (Araceae); tree philodendron, *Philodendron bipinnatifidum* (Araceae); Madagascar periwinkle (commonly called 'vinca'), *Catharanthus roseus* (Apocynaceae); English ivy, *Hedera helix* (Araliaceae); Boston fern, *Nephrolepis exaltata* (Lomariopsidaceae); and zinnia, *Zinnia elegans* (Asteraceae). Weeds evaluated were: common dayflower, *Commelina communis* (Commelinaceae); Asiatic hawksbeard (oriental false hawksbeard), *Youngia japonica* (Asteraceae); pink wood sorrel, *Oxalis debilis* (Oxalidaceae); Florida pellitory, *Parietaria floridana* (Urticaceae); dichondra, *Dichondra carolinensis* (Convolvulaceae); wild poinsettia (Mexican fireplant), *Poinsettia heterophylla* (Euphorbiaceae); Florida beggarweed, *Desmodium tortuosum* (Fabaceae); Spanish needles (common beggarstick), *Bidens pilosa* (Asteraceae); and common ragweed, *Ambrosia artemisiifolia* (Asteraceae). Also, floral mix 1 consisted of St. Augustinegrass, purple queen, coleus, common dayflower, and dichondra in approximately equal quantities and totaling about 2 g. Floral mix 2 consisted of peace lily, English ivy, Boston fern, lubbersiana, and wood sorrel in the same manner. Native flora often associated with humid environments that might be consumed by snails also were assessed: perforated ruffle lichen, *Parmotrema perforatum* (Parmeliaceae), cartilage lichen, *Ramalina* sp. (Ramalinacae), and steerecleus moss, *Steerecleus serrulatus* (Brachytheciaceae).

A small test was also conducted using older snails of intermediate age (1.0–1.5 g) initially cultured on romaine lettuce to ascertain whether or not plant suitability displayed by young snails was consistent with feeding by these older (larger) snails. The older snails ($n = 15$ per host plant) were cultured individually and weighed in the same manner as the younger snails for 3 wk, but using only a few prospective host plants: romaine lettuce, peace lily, lubbersiana, tree philodendron, coleus, purple queen, and Asiatic hawksbeard.

The effect of plant condition (age) on snail feeding preference was assessed by measuring leaf consumption (change in wet weight) by snails presented simultaneously with a green (generally young and apical) and a yellowing or yellow (senescent and basal) leaf from one of 4 plant species. Five young snails (about 0.25 g each) cultured on romaine lettuce were confined in each of 20 replicate containers with both a young and a senescent leaf in 1 L covered plastic containers for 24 h at 26 °C to determine consumption. The foliage was acclimated to a saturated environment (tight container with moist paper towels) for 24 h before exposure to the snails, and the foliage weighed before and after exposure to the snails to assess consumption (preference) as determined by foliage wet weight loss. Plant foliage was presented on moist filter paper to keep the foliage fresh. The four plant species assessed were Florida beggarweed, wild poinsettia, Spanish needles, and water primrose, *Ludwigia octavalis* (Onagraceae). All commonly have both senescent (basal) and vigorously growing (apical) foliage present in late summer when snails are actively feeding and growing. Relative acceptance was analyzed with two-way ANOVA using plant species and plant age as variables. Differences in foliage consumption among species were assessed with the Bonferroni Multiple Comparison Test (GraphPad Prism, GraphPad Software, San Diego, California), and preference for young versus senescent tissue for each plant species with a paired *t*-test (GraphPad Prism).

In a second, related preference study, I assessed relative preference of the snails for these plant species by presenting one young leaf of all 4 plant species simultaneously (matched for similar size) to two snails (about 0.5 g each) in the manner described above for assessment of preference in relation to plant condition. Consumption (wet weight loss) of each leaf was compared with one-way ANOVA and the Bonferroni multiple comparison test. The number of replicate containers for this test was 15.

Potential foliage consumption rates were determined in relation to temperature using romaine lettuce as a substrate. After being cultured at 26 °C, individual snails were cultured with lettuce in 500 ml cups and acclimated to two temperatures (24 and 32 °C) for 48 h, and then their individual consumption rates were determined for two consecutive nights. These temperatures were chosen to represent the typical upper and lower temperatures that snails might experience during summer months in southern Florida. The daily foliage consumption was traced with pencil and paper, excised, and the area consumed determined with a LI-COR 3000 leaf area meter (LI-COR, Lincoln, Nebraska). Leaf area removal was assessed because this is the parameter that is usually of most concern to producers of ornamental plants, though it can be difficult to assess accurately for some types of foliage. Romaine lettuce leaf area can be converted to approximate wet weight of tissue consumed using the formula $1\ cm^2 = 0.2\,9 \pm (0.06)$ g [mean ± (SD)] (Capinera, unpublished). A total of 10 snails were assessed at each temperature for 2 consecutive nights and at about 14 day intervals over the course of their development from hatching to maturity, which required about 120 days. Leaf area consumption ($n = 150$ for each temperature) was plotted against the wet weight of the snail to determine how snail size (weight) affected consumption and to portray the effects of temperature on consumption. Linear and polynomial regression equations were assessed with GraphPad Prism (GraphPad Software, San Diego, California) and R^2 values were used to estimate the best fit.

2.2. Bait studies

The effects of several snail and slug baits were assessed under laboratory conditions, with measurements made on both survival and foliage consumption during 5 d of exposure to baits plus a food source.

The baits included 2 metaldehyde-containing baits: Ortho Bug-Geta Plus Snail, Slug, and Insect Killer (Ortho, Columbus Ohio), containing 2% metaldehyde and 5% carbaryl; and Corry's Slug and

Snail Pellets, containing 3.25% metaldehyde (Matson LLC, North Bend, Washington). Two iron-based products evaluated were Ortho Ecosense Slug and Snail Killer, containing 1% iron phosphate (Ortho, Marysville, Ohio) and Ferrox Slug and Snail Bait, containing 5% sodium ferric EDTA (Neudorff North America, Emmerthal, Germany). Also evaluated was Niban Granular Bait containing 5% orthoboric acid (Nisus Corporation, Rockford, Tennessee). For all assessments, 5 snails of uniform size were confined with about 6 cm^2 of romaine lettuce (control containers), or lettuce plus 0.25 g of one of the five aforementioned baits, in a covered 500 ml plastic cup with a small piece of moist paper towel.

For bait comparison studies, four replicate containers held at 26 °C were used for each treatment, with starting dates staggered by 3 d for each replicate. Thus, mean snail wet weight varied from about 0.5 to 2.0 g over the course of the 4 replicates. Snail mortality and consumption were checked daily for 5 d, with the lettuce replaced daily and consumption measured by weight loss. Wet weight loss is somewhat more accurately measured than leaf area, and perhaps less inherently variable due to differing leaf thickness. Lettuce was weighed and replaced daily, and dead snails were removed but not replaced. A second control was established with lettuce but without snails to assess weight loss of lettuce in the containers due to transpiration, but less than 2% weight loss occurred so these data were ignored.

Mortality and consumption data in the bait comparison studies were analyzed with 2-way repeated measures ANOVA (GraphPad Prism). The factors were bait treatments and time (days post-treatment). The Bonferroni Multiple Comparison Test was used to assess significant differences among treatments. The % mortality data, expressed as proportions, were transformed to arcsin square root +0.5 before analysis.

After observing the results of the bait study, I determined that a follow-up study was needed to assess the mortality induced by Niban, and resultant plant consumption, over a longer period of time, because mortality was observed only at the very end of the 5 d study. This suggested to me that given a few more days of observation, Niban might prove to be an effective molluscicide. In this case, consumption and survival of 5 snails in each of 6 separate containers were evaluated for the Niban plus lettuce and a control (lettuce only) as described above. These studies deviated from the aforementioned protocol only in snail size (all initially about 0.25 g) and period of assessment (data were recorded every 2 days for 14 days). I also determined wet weight of surviving snails after 14 days. The consumption, % mortality, and final wet weight of surviving snails from Niban-containing and control containers were analyzed with Student's t-test. The % mortality data were transformed as previously noted.

3. Results

3.1. Host plants and foliage consumption

Relative to the plant species tested, romaine lettuce was superior for young snail weight gain, followed by wild poinsettia, common ragweed, Asiatic hawksbeard, zinnia, Florida beggarweed, and Madagascar periwinkle (Fig. 1). Snails fed all other plants displayed poor growth. Most diets elicited consistent snail performance among replicate snails, but those fed Madagascar periwinkle displayed more variable growth patterns than other diets. For unknown reasons, some snails grew rapidly on a diet of periwinkle whereas others did not.

I also observed an interesting pattern of early wet weight gain among snails fed relatively unacceptable diets. In many cases, the young snails initially fed upon whatever plant they were provided, and displayed increases in weight of 10–40% after one week, but thereafter began a weight decline or remained at a relatively constant weight for the 5 weeks of the study. For example, the young snails fed initially on St. Augustinegrass, rasping long strips of tissue from the surface of the foliage, but thereafter did not feed. Purple queen, peace lily, coleus, common dayflower, Spanish needles, and

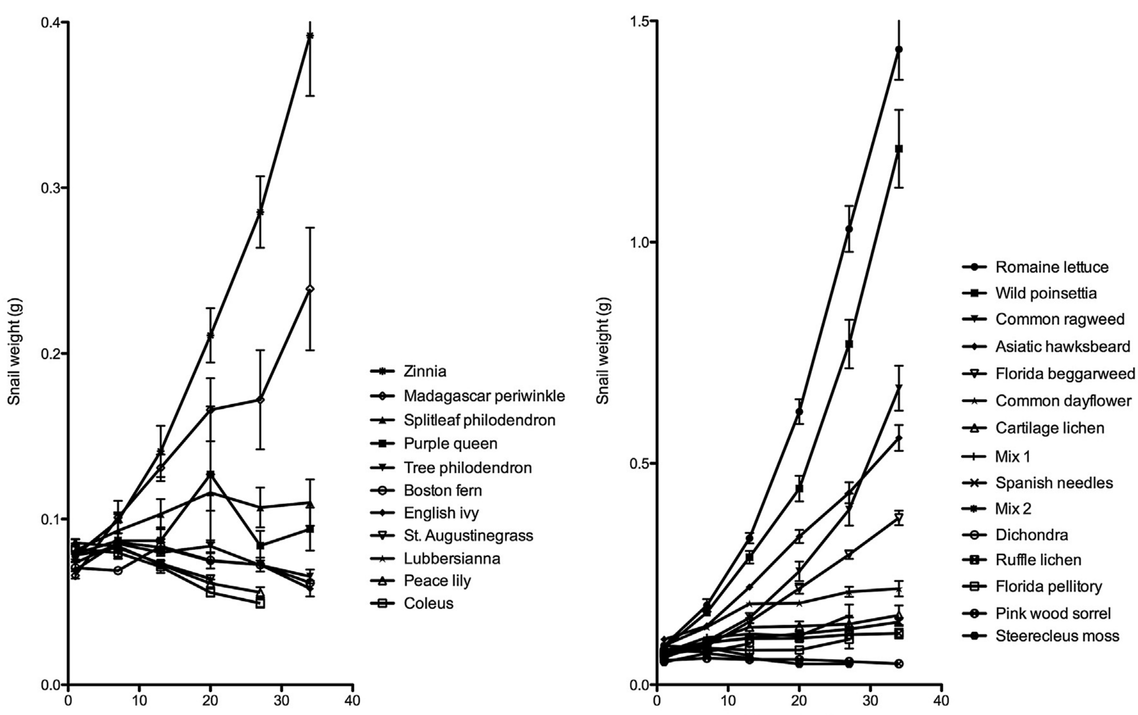

Fig. 1. Wet weight change of young *Z. provisoria* during the first 5 wk of life when provided with different host plants: (left) ornamental plants; (right) other plants. Error bars are SE. Note change in scale between left and right figures.

steerecleus moss were among those diets that initially supported snail weight increase but eventually proved unacceptable. In contrast, snails completely avoided feeding on Boston fern, English ivy, pink wood sorrel, and dichondra. Plant mix 1 allowed slight weight gain initially, apparently based on limited acceptability of dayflower, coleus, and purple giant, but over the course of the study the snails did not thrive, attaining 50% mortality after 4 wk. Plant mix 2 allowed no growth. The lichens were not very suitable for weight gain; snails fed ruffled lichen gained about 50% by week 5, and those fed cartilage lichen gained about 100%, but these snails remained quite undeveloped.

Older snails displayed similar dietary habits as younger snails. They readily consumed lettuce and gained weight, increasing from a mean of 1.31 (0.07) g (SE, wet weight) to 1.86 (0.7) g, a 42.2% increase in 3 wk. As was the case with young snails, Asiatic hawksbeard was intermediate in suitability, allowing the snails to gain 25.1%. As observed with the younger snails, the older snails consumed only small amounts of peace lily, lubbersiana, tree philodendron, and coleus, losing weight after a small initial gain (weight change of −27.1, −23.7, −26.7, and −25.4% after 3 wk). The most interesting host was purple queen; as with the younger snails, they ate the foliage readily, but lost weight, declining 6.3% in 3 wk.

Snails discriminated among plant species and between green (young) and yellow (senescent) plant tissue when provided with choices (Table 1). When afforded opportunity to choose among 4 species, they consumed significantly more wild poinsettia and Florida beggarweed than Spanish needles and water primrose ($F = 44.54$, df = 3,56; $P < 0.0001$). When provided opportunity to choose between green (young) and yellow (senescent) tissue, they similarly displayed significant differences in consumption. Both plant species ($F = 63.80$, df = 3,152; $P < 0.0001$) and plant age ($F = 19.53$; df = 1,152; $P = 0.0014$) effects were statistically significant, as was the interaction ($F = 11.76$; df = 3,152; $P < 0.0001$). They chose green (young) tissue of preferred plants (wild poinsettia, Florida beggarweed), but yellow (senescent) tissue of non-preferred plants (Spanish needles, water primrose).

Predictably, foliage consumption increased with age (wet weight) at both 24 and 32 °C. However, the rate of consumption was higher at the lower temperature. The pattern (Fig. 2) of consumption at 24 °C was well described by a second order polynomial equation ($R^2 = 0.643$). At 32 °C, the relationship was less satisfactory ($R^2 = 0.302$), but also non-linear. At 24 °C, mean peak consumption was about 40 cm^2 or 12 g wet weight of foliage/day. At the less favorable high temperature of 32 °C, mean peak consumption was reduced by about 50%, to only 20 cm^2 or 6 g wet weight/day. Interestingly, a major difference in the feeding behavior of the snails was that at the higher temperature they were more likely to avoid feeding. At 32 °C, they might feed quite well on one day and much less so on another, but feeding was more consistent at the lower temperature. Maximum consumption by individual snails was appreciably greater at both temperatures, with some individuals consuming up to 60 cm^2 of leaf area or 17 g/day at 24 °C and up to 40 cm^2 or 12 g/day at 32 °C. At both temperatures, snails ate proportionally more foliage (cm^2 or g foliage/g snail/day) when young, with the rate of consumption diminishing with age (wet weight) (Fig. 3).

Table 1
Mean (SE) foliage consumption (mg wet weight) by snails provided with simultaneous choice between four plant species, or between young (green) and senescent (yellow) foliage within a single plant species.

Test type	Plant species			
	Wild poinsettia	Florida beggarweed	Spanish needles	Water primrose
Between ages				
Young	98.4 (6.9)a*	71.4 (8.2)b**	16.0 (2.6)c*	0.5(0.02)c**
Senescent	51.0 (6.9)a	47.7 (7.5)ab	30.7 (4.4)ab	7.8(2.5)b
Between species	72.9 (8.6)a	52.3 (6.3)a	3.2 (1.9)b	0.2(0.4)b

Means within a row followed by different letters denote significant differences among species ($P < 0.05$) by the Bonferroni Multiple Comparison Test.
Means within a column followed by asterisk denote significant differences between plant age (condition) within a plant species (* = $P < 0.05$; ** = $P < 0.01$) by the Bonferroni Multiple Comparison Test.

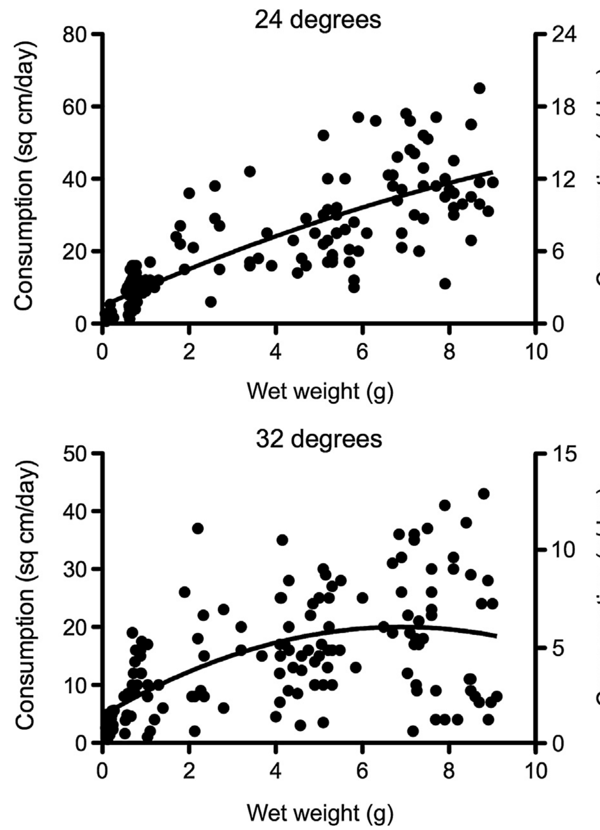

Fig. 2. Romaine lettuce consumption (leaf area and wet weight) by *Z. provisoria* in relation to two constant temperatures (°C). Second order polynomial for 24 °C is $y = 4.839 + 5.409x - 0.1446x^2$ ($F = 270.5$; df = 1,148; $P = <0.0001$). Second order polynomial for 32 °C is $y = 4.723 + 4.429x - 0.3209x^2$ ($F = 50.47$; df = 1,148; $P = <0.0001$).

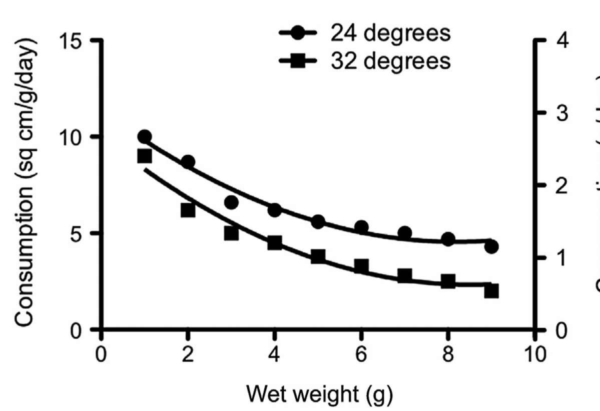

Fig. 3. Relative consumption rate (leaf area and wet weight) by *Z. provisoria* at two constant temperatures (°C). Second order polynomial for 24 °C is $y = 11.37 - 1.665x + 0.1016x^2$ ($F = 21.71$; df = 1,6; $P = 0.0035$). Second order polynomial for 32 °C is $y = 10.01 - 1.805x + 0.1060x^2$ ($F = 13.99$; df = 1,6; $P = 0.0096$).

3.2. Bait studies

In the bait comparison study, bait effects on mortality were highly significant ($F = 15.76$; df = 5,18; $P < 0.0001$). Time was also a significant factor ($F = 24.96$; df = 4,72; $P < 0.0001$), and the interaction was significant ($F = 2.50$; df = 20,72; $P = 0.0025$).

Mortality among control snails was low, averaging 10.0(5.8)% (SE) 5 d post-treatment (Fig. 4). Induction of mortality was similar for most bait products. The metaldehyde-containing baits, Ortho Bug-Geta Plus and Corry's, displayed significantly greater mortality ($P < 0.01$) relative to the control 2–5 d post-treatment. The iron-based products, Ferrox and Ortho Ecosense, induced significantly higher mortality ($P < 0.01$) relative to the control from 3 to 5 d post-treatment, but not earlier. In contrast, the boric acid-containing Niban failed to induce significant mortality ($P = >0.05$) relative to the control during all 5 d of the study. Niban also induced lower levels of mortality than Corry's on 1–5 d post-treatment ($P < 0.01$), than Ortho Bug-Geta Plus on 2–5 d post-treatment ($P < 0.01$), and the Ferrox and Ortho Ecosense bait treatments 3–5 d post-treatment ($P < 0.01$).

Consumption also varied significantly due to bait treatments ($F = 8.83$; df = 5,18; $P = 0.0002$), and time was a significant factor ($F = 5.95$; df = 4,72; $P = 0.0003$). The interaction was not significant ($F = 0.48$; df = 20,72; $P = 0.9653$).

Consumption by groups of control snails did not decrease over the 5 d of the study, and averaged 1.2–1.9 g/day. Consumption among groups of bait-treated snails decreased in time, partly due to mortality, but apparently also due to physiological stress. Consumption among Niban-treated snails averaged 0.4–0.9 g/day, less than the control containers; however, relative to the control, Niban-treated snails displayed significantly depressed consumption ($P < 0.05$) only 5 d post-treatment. Ferrox, Ortho Ecosense, Ortho Bug-Geta Plus, and Corry's greatly suppressed consumption relative to the control ($P < 0.05$) throughout the study. There were few significant differences in consumption ($P > 0.05$) among the molluscicide-containing bait treatments.

In the second study involving Niban, consumption was significantly affected by treatment ($F = 45.90$; df = 1,10; $P < 0.001$), though time was not a significant factor ($F = 1.27$, df = 6,60; $P = 0.28$). The treatment–time interaction was also significant ($F = 2.43$; df = 6,60; $P = 0.036$). Over most of the 14 d trial, a decrease in foliage consumption of about 50% was evident. Consumption 2 d post-treatment, though averaging lower, was not significantly decreased by Niban treatment, but lettuce consumption was significantly lower ($P < 0.01$–0.0001) on the subsequent six assessments when Niban was present (Fig. 5). This is consistent with the previous study, where it took 5 d for a significant difference to be observed.

Mortality was also affected by the Niban treatment ($F = 4.96$; df = 1,10; $P = 0.05$), but time ($F = 5.52$; df = 6,60; $P = 0.0001$) and the treatment–time interaction ($F = 5.52$; df = 6,60; $P = 0.0001$) were also significant. Delayed mortality was again observed in the Niban treatment, and there was not a statistically significant level of mortality until 12 d ($P < 0.01$) and 14 d ($P < 0.001$) post-treatment. Mean cumulative % mortality (SE) was 0 (0), 3.3 (3.3), 3.3 (3.3), 10.0 (6.8), 16.7 (8.0), 30.0 (11.2), and 33.3 (9.8) for days 2, 4, 6, 8, 10, 12, and 14, respectively. There was no mortality among control (untreated) snails. Surviving snails also seemed to be affected by Niban exposure, as their mean wet weight after 14 d, 619 mg, was significantly ($t = 6.58$; df = 47; $P < 0.0001$) less than among control snails, 972 mg.

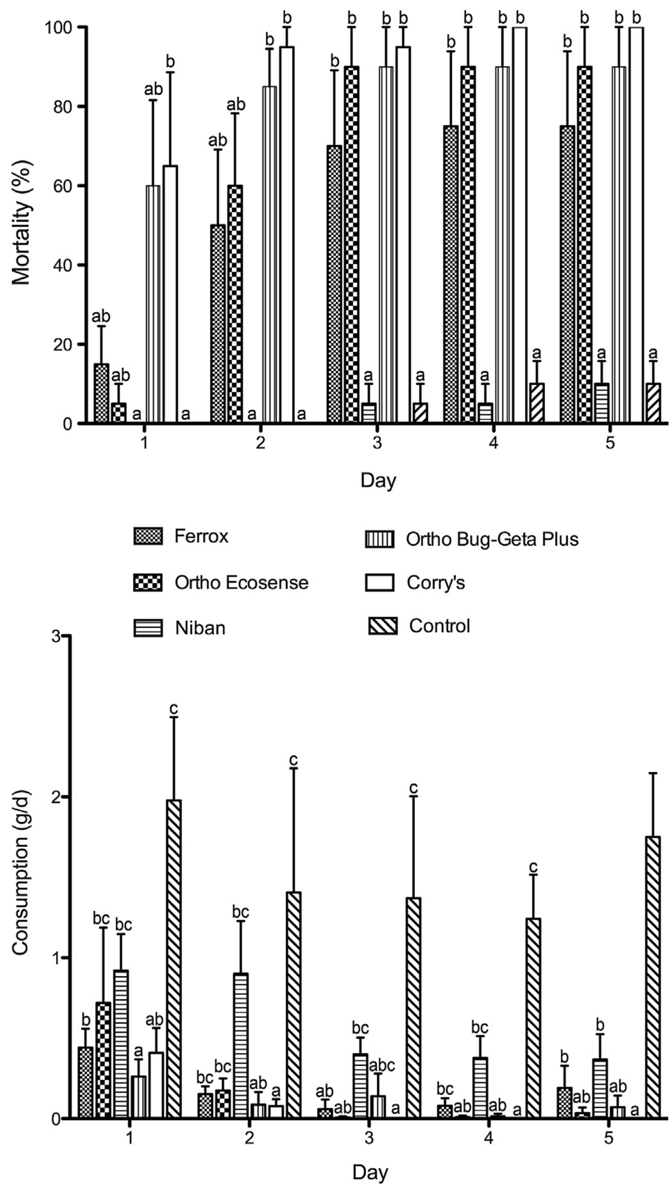

Fig. 4. Mortality and consumption (wet weight) by *Z. provisoria* over a 5 d period when provided with molluscicide-treated baits. Error bars are SE. Means topped with the same letter are not significantly different ($P > 0.05$) by the Bonferroni Multiple Comparison Test.

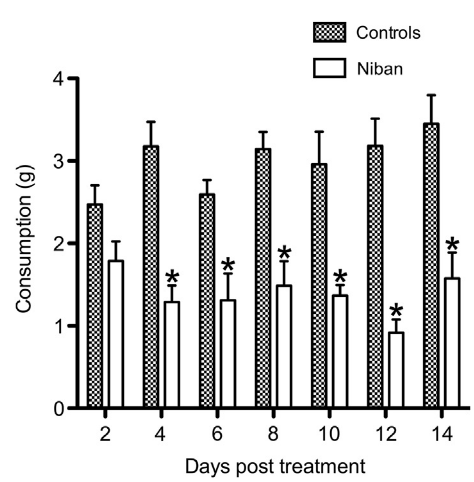

Fig. 5. Suppression of foliage consumption (wet weight) by groups of *Z. provisoria* over a 14 d period when provided with a boric acid-based pesticide (Niban). Error bars are SE. Mean consumption values of Niban-exposed snails topped with an asterisk (*) are significantly different from the corresponding control ($P < 0.05$) by Student's *t*-test.

4. Discussion

4.1. Host plants and foliage consumption

Although possessing a reputation for causing plant damage in Florida, plants varied considerably in suitability for growth of young *Z. provisoria* snails. Romaine lettuce allowed rapid weight gain, but most plants evaluated, both wild and cultivated, were considerably less supportive of growth and survival. Several weeds were favorable for growth, suggesting that untended environments could lead to snail problems in adjacent ornamental plantings, but the extent of the host range remains largely undocumented. Confounding the assessment of suitable host plants is the ability of some herbivores to feed on suboptimal plants when faced with starvation. This phenomenon is common among polyphagous species. When confronted with shortage of food their 'host range' will expand, and they may feed on plants not normally eaten. When older snails were provided with a no-choice situation they ate small amounts of peace lily, lubbersiana, tree philodendron, and coleus, plants that were unsuitable for growth of young snails. They did not consume large amounts, and did not gain weight, but they consumed enough to cause cosmetic injury. More enigmatic was suitability of purple queen. It was eaten to a limited degree by young snails but it did not support weight gain. The older snails ate it readily but also did not gain weight. Apparently this plant lacks feeding deterrents but also lacks the nutritional characteristics necessary for snail growth. The only pattern to emerge from these studies was the apparent relative suitability of plants in the family Asteraceae.

Senescing leaves often are reported to be preferred over both green plant material and dead tissue. Presumably this is due to the lower toxin content of senescing versus green leaf tissue (Speiser, 2001). This interpretation is consistent with the observations reported here, wherein yellow (more senescent) tissue from less preferred plants was favored. Even so, only small amounts of leaf tissue from the less preferred plants was consumed, so availability of senescent tissue from nonpreferred plants might not favor snail growth. In strong contrast, green tissue was selected over yellow tissue from the more preferred plants. Thus, *Z. provisoria*, unlike some terrestrial molluscs, seems to favor green plant material, though it is clearly selective in its dietary habits. Plant age-related shifts in feeding behavior also were reported by Fenner et al. (1999), who studied plant selection by the slug *Deroceras reticulatum* (Müller), and reported that host selection behavior varied with palatability. Specifically, from among less preferred plant species, the seedlings were selected by *D. reticulatum*, but from among more preferred plants tested, the mature plants of the same species were more often eaten. Speiser (2001) reviews other examples of changes in host selection.

Foliage destruction potential, based on consumption of romaine lettuce, was appreciable. Mature snails, when feeding on a highly acceptable host plant, consumed about 40 cm^2 or 12 g/day when held at 24 °C. This equates roughly to consumption of an entire mature leaf of lubbersiana, which typically average about 45 cm^2, or nearly half the leaf of a mature peace lily, which average about 100 cm^2 when mature. Feeding rates were reduced at high temperatures throughout the development of the snails, so damage levels could be expected to be quite variable, even for a single snail size class and a uniform host. However, even at unusually high temperatures, appreciable consumption can occur.

Relative consumption rate (cm^2 foliage/ or g/g snail/day) diminished with age (wet weight) of the snails. Age-related changes in consumption rate are known in other molluscs (Jennings and Barkham, 1976) and in insects. For the slug *Arion ater* (Linnaeus), Jennings and Barkham (1976) reported that immature slugs had twice as great a relative consumption rate as mature slugs. In caterpillars, the relative consumption rate, relative metabolic rate, relative growth rate, and approximate digestibility diminish as the insects increase in size. These trends are attributed, in part, to less selective feeding by the larger animals. Although small animals feed selectively, avoiding less digestible material, as the herbivores grow they consume less digestible leaf veins (Parra et al., 2012).

4.2. Bait studies

Plant damage by terrestrial molluscs can be minimized by killing the animals quickly, or by interfering with their feeding. Although metaldehyde-containing baits reduced feeding almost immediately due to induction of mortality, the iron-containing and boric acid-containing baits Ferrox, Ortho Ecosense, and Niban also were associated with reduced foliage feeding even before mortality was evident. This was most evident in Niban, where feeding was suppressed beginning 4 d post-treatment despite the lack of significant mortality until 12 d post-treatment. Though the products tested were different in the rate of mortality induction, all eventually suppressed feeding. Niban was the slowest acting product evaluated, and least effective at foliage protection, though it clearly disrupted snail feeding and growth, and induced a moderate level of mortality by 14 d post-treatment. In recent years, iron phosphate baits have been found to be effective at reducing plant damage, and often are competitive with metaldehyde-based products (e.g., Speiser and Kistler, 2002; Nash et al., 2007; Rae et al., 2009) from the perspective of molluscicidal performance, and superior from the perspective of environmental safety due to lower vertebrate toxicity. Clearly, increased mortality and reduced feeding damage induced by iron phosphate and metaldehyde products in these tests involving Cuban brown snail were consistent with reports on other molluscs. However, there seems to be no information on the effectiveness of sodium ferric EDTA and boric acid for snail control available in the scientific literature, so those aspects of these studies are novel.

4.3. Conclusions

Cuban brown snail, *Z. provisoria*, can cause significant leaf damage due to its large size and broad folivorous dietary habits. Cuban brown snail is considered to be polyphagous because the adults occasionally damage a large number of plants. However, many plants are not suitable for growth of these snails, and the occasional depredations of flowerbeds and ornamental plants probably are not indicative of their normal feeding habits. Weeds are likely important in maintenance of populations. Leaf consumption (cm^2 or g/day) increased as snails increased in size, but relative consumption (cm^2 or g foliage/g snail/day) decreased. Though tropical in origin, leaf feeding by *Z. provisoria* is suppressed by high temperatures. All snail baits controlled *Z. provisoria* during the course of the study, though they differed in how quickly they induced mortality. Metaldehyde-containing baits worked most quickly, iron-based baits were intermediate, and the boric acid product (Niban) was slowest. All baits were effective at suppressing foliage consumption, though Niban required 4–5 d to induce significant reduction in leaf consumption.

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