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Distribution, Host Plants, and Life Cycle of *Melanaspis deklei* (Hemiptera: Coccoidea: Diaspididae) in South Carolina, USA

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Abstract: The armored scale, *Melanaspis deklei* Deitz & Davidson (Coccoidea: Diaspididae), was reported for the first time in the state of South Carolina, U.S.A., in 2008. A study was conducted in 2009 to 2013 to 1) better understand its life cycle, 2) document its distribution in the states of Georgia (GA), North Carolina (NC) and South Carolina (SC), and 3) document its host range in the urban landscapes of SC. We surveyed 74 locations and found *M. deklei* in urban landscapes of NC, SC and GA, including areas in and surrounding the major urban centers of Wilmington (NC); Myrtle Beach, Georgetown, Charleston, Beaufort and Hilton Head Island (SC); and Savannah (GA). Within this area, *M. deklei* was found to only infest and damage wax myrtles (*Myrica cerifera* (L.) Small; Myricaceae), although other known suitable host plant genera (e.g., *Agave* sp., *Ilex* spp., *Sambucus* sp., *Ditrysinia* (= *Sebastiania*) sp. and *Viburnum* spp.) were present in the same landscapes. In SC, three overlapping generations of *M. deklei* were detected annually in 2009 and 2010, with the majority of females overwintering as non-reproductive adults. Crawlers were present from May to December with peak emergence occurring in June, August and October-November.

Keywords: *Myrica cerifera*, *Ilex*, *Viburnum*, urban landscape, ornamental plants

Introduction

The armored scale, *Melanaspis deklei* Deitz & Davidson, is distributed in Mexico, the southeastern United States (the states of Florida, Georgia and South Carolina), and the West Indies (Deitz, Davidson 1986, Chong *et al.* 2009). It was not known to be a pest of horticultural or agronomic crops until its pest status was reported on wax myrtle (*Myrica cerifera* (L.) Small; Myricaceae) grown as ornamental plants in the urban landscapes of South Carolina (Chong *et al.* 2009). All life stages of *M. deklei* feed on the twigs (and on leaves during heavy infestations) of wax myrtles, causing the surrounding tissues to die and collapse. The symptoms of the initial infestation include circular purplish necrosis around feeding sites. Localized dieback of the infested twigs or branches, and necrosis of canopy appear as the infestation progresses. If scale insect populations are not managed, the entire wax myrtle shrub may die within months or years, depending on the initial health and size of the infested plants. The loss of shrubs and impairment of aesthetic value are becoming a significant management problem for urban landscapes in coastal communities of South Carolina (Chong *et al.* 2009).

Chong *et al.* (2009) reported that the applications of neonicotinoids and acephate (via foliar sprays or soil applications) were not effective in reducing *M. deklei* populations. However, a trend for a

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reduction in *M. deklei* abundance was detected in the second year of application using paraffinic oil and pyriproxyfen (applied as foliar or topical sprays). Crawlers and young nymphs of scale insects are most susceptible to topical applications because of the lack of protective tests. Therefore, landscape-care professionals have been advised to make repeated applications of paraffinic oil and pyriproxyfen during the period of crawler emergence. However, the life history of *M. deklei* was unknown previously and this hindered the development of a properly timed and effective insecticide application program.

Melanaspis deklei was reported to feed on *Agave* sp., an evergreen composite (Asteraceae), *Ilex* sp. (Aquifoliaceae), *Iva* sp. (Asteraceae), *M. cerifera*, *Persea americana* Mill (Lauraceae), *Sambucus* sp. (Caprifoliaceae), *Sebastiania* sp. (Euphorbiaceae), *Sida rhombifolia* L. (Malvaceae) and *Viburnum* spp. (Caprifoliaceae) (Deitz, Davidson 1986). Some of the known suitable host species or genera, such as *Agave*, *Ilex*, *Viburnum* and *M. cerifera*, are common ornamental plants in urban landscapes of the southeastern United States (Halfacre, Shawcroft 1989, Dirr 2011). While *M. deklei* was collected only on wax myrtles in South Carolina (Chong *et al.* 2009), no consistent and concerted survey has been undertaken to document the presence and pest status of *M. deklei* on other common and potentially suitable ornamental plant taxa.

Melanaspis deklei was reported in northern and central Florida and central Georgia (Deitz, Davidson 1986), and in Beaufort, Georgetown and Horry Counties in South Carolina (Chong *et al.* 2009). It is not known if *M. deklei* is also a pest of wax myrtle shrubs in communities of Georgia and North Carolina that border on South Carolina. While most infestations by *M. deklei* are documented on wax myrtle shrubs grown in urban landscapes, the presence and pest status of *M. deklei* are unknown for plants grown in commercial ornamental plant nurseries. Whether these scale insects are established in nurseries may have significant implications. First, detection may require growers to better manage the scale insects to reduce their introduction into the landscapes. Second, regulatory actions to restrict the sale and transport of infested plants may be considered if the species is detected in production nurseries.

This study has three objectives: 1) to better understand the life cycle of *M. deklei*; 2) to document the distribution of *M. deklei* in Georgia, North Carolina and South Carolina; and 3) to document the host range of *M. deklei* in urban landscapes of South Carolina. Identification of the pest's distribution, its host range and timing of crawler emergence will aid in the development of a management program against *M. deklei* in urban landscapes of the southeastern United States.

Materials and Methods

Life Cycle of *Melanaspis deklei*

Seasonal abundance of *M. deklei* was investigated in the landscapes of a golf-residential community in North Myrtle Beach, South Carolina, from January 2009 to December 2010. Twenty-two wax myrtle shrubs (1-2 m in height and width) planted singly were selected in 2009 for monitoring population abundance based on the presence of moderate damage by *M. deklei*, namely necrosis of the twigs and canopy. Landscape-care professionals pruned the wax myrtle shrubs monthly to maintain a form or appearance desired by the property owners. The shrubs' large size ensured that sufficient numbers of infested twigs were available for regular sampling. Ten shrubs survived to the end of the life cycle study in 2010.

Infested twigs (length 10-15 cm) were collected weekly from the four cardinal directions of each wax myrtle shrub beginning in January 2009. The twigs were stored in plastic bags and transported to the laboratory in an iced cooler. The samples were examined and live scale insects were counted under dissecting microscopes. Scale insect tests were flipped over with a pin and the viability of the scale insects was determined. Live insects were yellow, whereas dead ones were brown, black or absent. The numbers of live crawlers (dispersing first instars), 'whitecaps' (settled first instars), second-instar males (including the 'pre-pupa' and 'pupa') and adult females were counted and their densities (individuals per cm twig length) were calculated on each sampling date. The numbers of adult males on each sampling date could not be determined reliably due to their rarity, ephemerality and mobility.

Peak emergence periods of crawlers and the duration of each life stage were identified by plotting the density of crawlers and the presence of each stadium against sampling dates. Average daily temperatures were obtained from a public-access weather station maintained at the Grand Strand Airport (station identification code: KCRE), which is located about 10 km from the sampling site. Starting in 1 January of 2009 and 2010, daily degree-day units were calculated using the maximum-minimum method:

$$DD_i \max \frac{T_{max} \quad T_{min}}{2} T_{base}, 0 ,$$

where DD_i is the degree-day (in Celsius degree-day or DDC) accumulated on day *i*, T_{base} is the base temperature (set at 10°C), and T_{max} and T_{min} are the maximum and minimum daily temperature, respectively (Mcmaster, Wilhelm 1997). The accumulated DDC starting in 1 January were plotted against sampling dates in 2009 and 2010 and correlated with the first occurrence of crawlers of each generation.

Distribution of *Melanaspis deklei*

Seventy-four locations (12 ornamental plant nurseries and 62 urban landscapes) in Georgia (six counties), North Carolina (five counties) and South Carolina (14 counties) were sampled to determine the distribution of *M. deklei* in these three states. The locations were selected based on the presence of wax myrtle shrubs and were sampled between August 2008 and August 2013. All wax myrtle shrubs at each sampled location were examined and twigs and leaves harboring armored scale insects collected. Samples were brought back to the laboratory in an iced cooler. Scale insect specimens were prepared, slide-mounted and identified based on the methodologies of Miller, Davidson (2005) and Deitz, Davidson (1986). Each location was designated as 'infested' or 'not infested' based on the results of the survey and identification.

Host Plants of *Melanaspis deklei*

Five commercial and residential landscapes or gardens in Myrtle Beach, South Carolina, were sampled in 2012 and 2013 for the presence of, and damage by, *M. deklei*. Landscapes were selected based on the presence of known host plant genera of *M. deklei*. Plants in the genera *Agave*, *Ditrysinia*, *Ilex*, *Myrica*, *Sambucus* and *Viburnum* were identified to species (those that could not be identified were placed in the 'Other' category) and sampled for the presence of *M. deklei*. Infested twigs and leaves were collected and the scale insects were prepared and identified as above. Potential damage by *M. deklei* (i.e. purplish feeding spots and necrosis of twigs and canopy) on each sampled plant also was recorded. Each plant was designated as 'infested' or 'not infested' and the infested plants were categorized as 'damaged' or 'not damaged'. The percentage of sampled plants that were infested and the percentage of infested plants that showed damage were calculated for each plant species and landscape.

Results and Discussion

Life Cycle of *Melanaspis deklei*

Melanaspis deklei females develop through two nymphal instars before reaching adulthood whereas the males complete four (first and second instar, 'prepupa' and 'pupa'). *Melanaspis deklei* is viviparous, similar to *M. inopinata* Leonardi (Katsoyannos, Stathas 1997). Crawlers disperse to new feeding sites. Late first instars have a distinctive thin waxy test or 'white-cap', secreted within the first 24 to 48 hours after settling at a feeding site (Miller, Davidson 2005).

Crawlers and 'white-caps' (i.e. the first-instar nymphs) were present from late May until mid-December in 2009 and 2010 (Fig. 1). In 2009, the first-generation crawlers emerged from late May to late June, the second generation from late July to early September, and the third generation from late October to early December. The earliest detection of first-generation crawlers in 2009 coincided with the accumulation of 614 degree-day units (DDC) (May 21), 1720 DDC for the second generation (July 30) and 2968 DDC for the third generation (October 29) (Fig.1). In 2010, the first-generation crawlers were present from late May to mid-July, the second generation from late July to mid-September and the third generation from mid-October to mid-December. Degree-day accumulation in 2010 when the first-generation crawlers were detected was 656 DDC (May 25), for the second generation 1753 DDC (July 26) and for the third generation 2968 DDC (October 12). Averaged across 2009 and 2010, degree-day accumulation for the first occurrence of the three generations was 635, 1736 and 2968 DDC, respectively.

The second-instar nymphs were present from June 2009 to mid-February 2010, with peaks in June until early July (first generation), August to the end of October (second generation) and late November to mid-February (third generation) (Fig. 1). In 2010, this stage was present from early June to mid-July (first generation) and August to the end of November (second generation). Our 2010 data did not cover the full duration of the third generation.

Adults were present throughout much of 2009 and 2010, and reproductive females were detected from mid-May 2009 until the beginning of January 2010 and from mid-May to the end of the sampling in December 2010 (Fig. 1). Non-reproductive females mostly were present from mid-February to mid-May 2009 and from mid-August 2009 to mid-May 2010.

The overwintering stage in *Melanaspis* varies among species. The majority of *M. deklei* overwintered as non-reproductive adult females, although second-instar nymphs also were present during the winter months (Fig. 1). *Melanaspis obscura* (Comstock) overwinters mostly as second-instar nymphs (Stoetzel, Davidson 1971, Ehler 2005) but overwintering adults have also been observed (Hendricks, Williams 1992). *Melanaspis tenebricosa* (Comstock), *M. smilacis* (Comstock) and *M. inopinata* overwinter as fertilized adult females (Stoetzel 1975, Katsoyannos, Stathas 1997). An additional example is *Diaspidiotus ostreaeformis* (Curtis), which typically overwinters as second-instar nymphs (Miller, Davidson 2005), but it over-

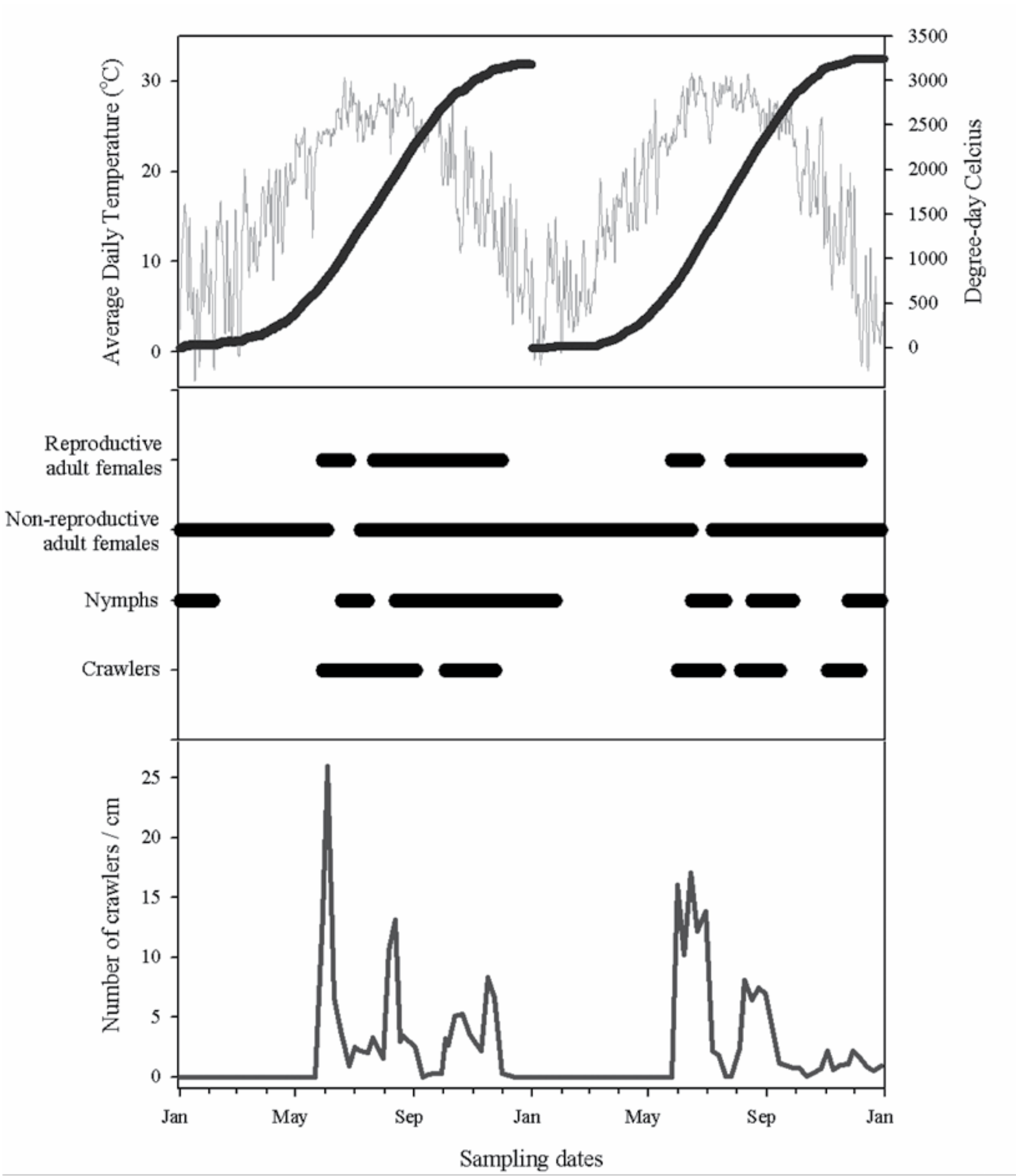

Fig. 1. The average ambient temperature, cumulative degree-day units (starting in 1 January), and the periods at which a specific life stage and crawlers of *Melanaspis deklei* was present in an urban landscape in Myrtle Beach, South Carolina, USA, in 2009 and 2010. The category 'Nymph' includes second-instar females, and second-instar, 'pre-pupal' and 'pupal' males

winters as first- and second-instar nymphs in New Zealand (Richards 1962, Mclaren 1989).

Chong *et al.* (2009) proposed a combination of cultural (pruning and disposal of infested plant materials), chemical (topical applications of horticultural or dormant oil, insect growth regulators and neonicotinoids) and biological (parasitoids and predators) management tools to reduce infestations of *M. deklei*. The life history information gathered in the present study has important implications for predicting the periods of crawler activity and determining the timing and frequency of insecticide applications.

A degree-day model is a useful tool for predicting the activity period of scale insect crawlers. The model of Potter *et al.* (1989) successfully predicted crawler emergence of *M. obscura* within two days (4.44°C as base temperature) of the actual dates in Kentucky, Indiana and Maryland. Similarly accurate result was obtained in Alabama by Hendricks, Williams (1992) for crawler emergence of *M. obscura* using the model of Potter *et al.* (1989). Because crawlers are the most vulnerable stage to insecticide application, accurate prediction of crawler activity will determine the effectiveness of a management program against *M. deklei*. Our degree-day model should prove to be useful in predicting the emergence of crawlers and should allow landscape-care professionals and arborists to schedule properly timed insecticide applications.

The voltinism of *M. deklei* differed from that of other species of the genus. *Melanaspis obscura*, *M. tenebricosa* and *M. smilacis* have only one generation per year (Stoetzel, Davidson 1971, Stoetzel 1975), whereas *M. deklei* has three overlapping generations per year in South Carolina. In each generation, crawlers of *M. deklei* were present for more than a month. In contrast, crawlers of *M. obscura* were active over two months in Maryland (Stoetzel, Davidson 1971), Kentucky (Potter *et al.* 1989) and Alabama (Hendricks, Williams 1992). Stoetzel (1975) reported that crawlers of *M. tenebricosa* and *M. smilacis* were active for about 1.5 months.

In the case of *M. deklei*, crawler emergence extended beyond the effective residual longevity of many insecticides (within 21 days after application) (Chong *et al.* 2009). Therefore, reapplication is needed within two to three weeks of the initial application to reduce the abundance of late-emerging crawlers. For *M. obscura*, *M. smilacis* and *M. tenebricosa,* which have only one generation per year, two applications per year may significantly reduce the scale insect abundance and damage. However, plant managers who intend to reduce *M. deklei* infestations might have to make as many as six insecticide applications per year to account for the prolonged crawler emergence periods over the three generations. An increased frequency of insecticide applications undoubtedly will increase material and labor costs as well as risks to non-target organisms, workers and the environment.

Distribution of *Melanaspis deklei*

Of the 74 locations surveyed, *M. deklei* was detected in 25 landscape sites. All were along the coast of Georgia, North Carolina and South Carolina (Fig. 2). Of the 11 counties surveyed in (Georgia 6, and North Carolina 5), *M. deklei* was detected only in New Hanover County in North Carolina (3 sites) and Chatham County in Georgia (3 sites). *Melanaspis deklei* was detected in 6 of 14 counties surveyed in South Carolina, with 6 sites in Horry County, 4 in Beaufort County, 4 in Charleston County, 3 in Georgetown County, 1 in Berkeley County and 1 in Dorchester County.

Melanaspis deklei was reported previously in Emanuel County, Georgia (Deitz, Davidson 1986). Its detection in Chatham County represents a new county report for the state. The detection of *M. deklei* in New Hanover County is the first state record for North Carolina. The present study confirms the presence of *M. deklei* in the coastal counties of South Carolina as previously reported by Chong *et al.* (2009).

Although infested nursery stock is a common way for scale insects to invade new areas (Beardsley, Gonzalez 1975), the absence of *M. deklei* in the nurseries surveyed appeared to exonerate the role of ornamental plant trade in expanding the distribution of *M. deklei* in the southeastern USA. It is likely that *M. deklei* spread within urban landscapes through a combination of biotic and abiotic mechanisms, e.g., wind dispersal of crawlers or movement of infested plant materials, debris, equipment and personnel. Although strict regulations and quarantines for scale insect may not be required currently, routine inspections of nurseries are still needed. Yet, many nurseries surveyed are near infested landscape sites and dispersal of this pest from infested landscape sites is highly probable. The nursery trade should be vigilant about infestation of their wax myrtle stocks by *M. deklei* and should implement appropriate management programs to eradicate or manage any scale insect population before plants are sold and transported to uninfested areas.

Host Plants of *Melanaspis deklei*

A total of 122 plants were sampled in the five surveyed landscapes or gardens, including *Agave americana* L. (N = 6), *Ditrysinia fruticosa* (W. Bartram) Govaerts & Frodin (N = 8), *Ilex cornuta* Lindl. (N = 16), *Ilex crenata* Thunb. (N = 6), *Ilex opaca* Aiton (N = 4), *Ilex verticillata* (L.) A. Gray (N = 4), *Ilex vomitoria* Sol. Ex Aiton (N = 4), *Ilex* x 'Nellie R. Stevens' (N = 3), an unidentified *Ilex* sp. (N = 1), *M. cerifera* (N = 32 managed and 15 unmanaged), *Sambucus canadensis* L. (N = 3), *Viburnum* x *carlcephalum* (N = 1), *Viburnum dentatum* L. (N = 2), *Viburnum japonicum* (Thunb.) Spreng. (N = 12), *Viburnum macrocephalum* Fort. (N = 1), *Viburnum obovatum* Walter (N = 2) and an unidentified *Viburnum* sp. (N = 2). However, *M. deklei* was detected only on wax myrtle. Among the 47 wax myrtle plants surveyed, 49% of the plants were infested and 53% of the infested plants were defined as damaged.

The original description of *M. deklei* (Deitz, Davidson 1986) did not identify particular host species within the genera *Sambucus, Viburnum, Agave, Ilex* and *Ditrysinia* (= *Sebastiania*). It is possible that, in our study, the species in these host genera were not the host plant species from which *M. deklei* originally was reported (Deitz, Davidson 1986).

More than 50% of managed wax myrtle shrubs exhibited damage by *M. deklei*, whereas only 8% of unmanaged shrubs exhibited similar damage. Some sucking insects perform better on stressed plants (e.g., Koricheva *et al.* 1998); thus, the differences in damage might have resulted from increased stress experienced by the severely pruned plants. Appropriate pruning increases the appearance and health of the plants and removes diseased or infested tissues; however, severe pruning – i.e. that removes a large amount of canopy and plant tissues - may be detrimental to plant growth, health and resistance or tolerance against insects or diseases (e.g., Grechi *et al.* 2008). Although there is no conclusive evidence demonstrating the detrimental effects of pruning on the health of ornamental plants, it might be assumed that severe and frequent pruning increases plant stress level. In addition, new tender shoots do not have enough time to recover from damage and are unable to create new canopy under high scale insect population pressure. Pruning usually promotes new growth on wax myrtles. *Melanaspis deklei* can have a disproportionally damaging effect on the new growth because new growth on pruned wax myrtles may not recover unless scale insect populations are reduced through pest management.

The life history of *M. deklei* in South Carolina contrasted with that other species of *Melanaspis* and has profound implications in its management. We developed a degree-day model for crawler emergence in South Carolina that should be tested in the southeastern United States. Plant managers could use the model to predict the time of crawler emergence and, thus, achieve the highest efficacy in insecticide application. The detection of *M. deklei* exclusively in urban landscapes does not preclude the possibility of its invasion into nurseries and, therefore, periodic inspection should be undertaken and all infestations should be managed immediately. Future studies to better understand the implications of stress (from pruning or other plant management practices) on population dynamics of the scale insects may benefit pest management practices and maintenance in ornamental plant production by elucidating the complexity of plant-insect interactions and providing information as to how to manipulate such interactions to maintain high quality plants. Wax myrtle was confirmed as the only host for *M. deklei* in the study area. However, further studies are needed to determine the host specificity *of M. deklei* among other reported host genera.

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