Expansion of Lobate Lac Scale Distribution into Oahu Forest Systems

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Abstract. The lobate lac scale, *Paratachardina pseudolobata*, was detected on Oahu in October 2012 at a botanical garden, located in the vicinity of the Honolulu International Airport. Early surveys done by HDOA and DLNR staff in the vicinity of detection areas and nearby forest reserves detected the scale on several species, including some native species. Given that the extent of lobate lac scale infestation was currently unknown on Oahu, a preliminary survey was carried out to update the host and habitat range of this invasive species in Oahu's native forests. Our surveys detected *P. pseudolobata* on four new native and three non-native host plants. The information collected from this survey will help determine the need for appropriate management efforts to avoid severe impacts and/or the loss of native species in Hawaii native ecosystems.

Key Words: Lobate lac scale, native plants, invasive species

The lobate lac scale (LLS), *Paratachardina pseudolobata* (Kondo & Gullan) (Coccoidea: Kerriidae), was found invading Florida in 1999. Between Florida and the Caribbean Islands the scale has been recorded on over 300 native and non-native plant species (Pemberton 2003, Howard et al. 2006). The scale was originally identified as P. lobata, however, evidence from minute morphological features and molecular analysis indicated that the scale was a new species (Kondo and Gullan 2007). Given this misidentification, initial efforts for a classical biological control program failed (host and biocontrol agent were not compatible) (Schoer et al. 2008). The native range of P. pseudolobata is currently unknown, but likely includes Tropical Asia (Schroer et al. 2008). The only current successful control method in Florida has been the use of insecticide drenches (Howard and Steinberg 2005).

In Hawaii, *P. pseudolobata* was detected in October 2012 at Moanalua Botanical Garden, located in the vicinity of the Honolulu International Airport. The scale was reportedly causing branch die back on an exotic *Ficus* species. Initial surveys by the Hawaii Department of Agriculture (HDOA 2013) at the time of detection identified the scale on 36 host plants, which included 6 native species (HDOA, unpublished data). Prior to the current survey, the scale has been recorded on over 96 host plants, including 12 native hosts (HDOA, unpublished data). The scale has not yet been reported on the other islands.

Female adults have a distinct convex x-shaped appearance that is 1.5–2 mm in length and width, and are encased in a hard dark reddish brown colored covering (Howard and Pemberton, 2003). Female scales are ovoviviparous and reproduce

Figure 1. High density of lobate lac scale infestation can lead to branch dieback on *Dodonaea viscosa* (left) and *Ficus* spp. (right).

parthenogenetically (Howard et al. 2006, Kondo and Gullan 2007). Males have not been observed in Florida or Hawaii. The first instar (crawler) is deep red, about 0.4 mm long, and has an elongate-oval shape (Howard and Pemberton 2003). By second instar, they develop into their characteristic lobate shape. A final molt produces the adult female. Entire developmental time takes 4–5 months from crawler to adult (Howard and Pemberton 2003).

Paratachardina pseudolobata is a pest of woody dicotyledonous plants. They typically colonize branches less than 2 cm in diameter and are found less frequently on the main stems (Howard et al. 2004). Newly emerged crawlers disperse onto the nearest available host or are easily dispersed by wind. Once they settle on a feeding site, they become sessile. High infestation can lead to an excess of sooty mold and branch dieback (Fig. 1) that can eventually lead to plant mortality (Howard et al. 2004).

The lobate lac scale is one of the newest invasive species in Hawaii. Although initial infestations were detected in urban areas, the scale has also been detected on native species. Given the level of infestation and impacts seen in Florida, this species has the potential to cause similar or greater devastating effects in native forests habitats in Hawaii. Here, we summarize results of a preliminary survey of LLS infestation across Oahu to define its current distribution. We mapped current areas of infestation and updated the list of native host plants in native forest areas on Oahu.

Methods

Preliminary surveys were done from the months of July to October 2014. The presence or absence of LLS on native plants was surveyed at 17 sites across the island of Oahu. Sites located in natural habitats were selected based on proximity to botanical gardens and other urban areas where the scale was already detected. Most sites were located across the central and southeastern portions of the Koolau mountain range (Table 1, Fig. 2). These sites included four botanical gardens, 11 forest sites with hiking trails, and two forest reserve areas without trails (Table 1). Efforts were made to inspect the majority of native woody plants accessible along the trails. However, since it would be difficult to inspect every single plant, plants that occurred throughout the trail were inspected approximately every 200 to 400 meters. Those that oc-

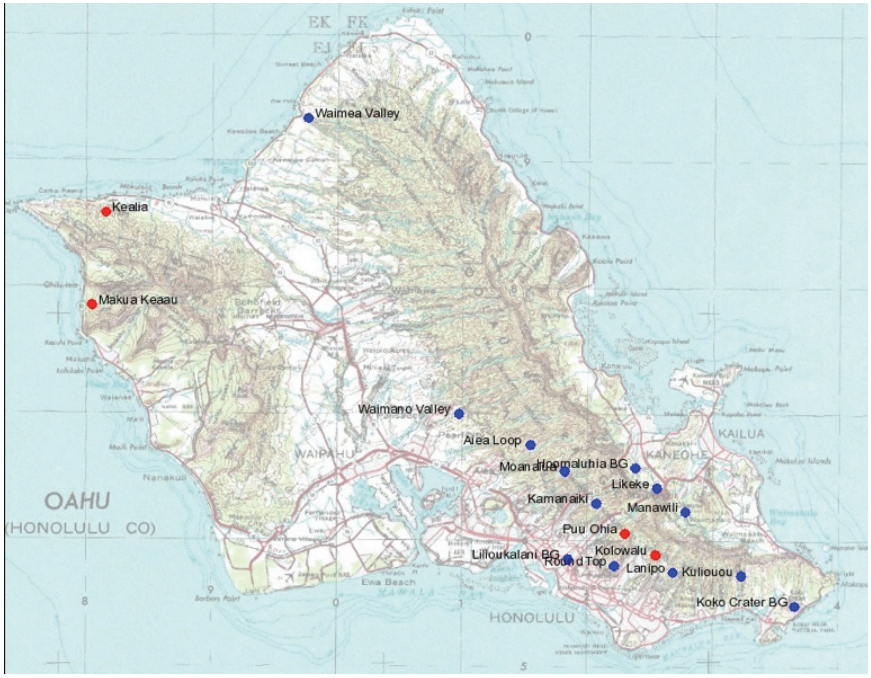

Figure 2. Location of sites for lobate lac scale survey on the island of Oahu. Red dots indicate trail/sites where the scale was not found. Blue dots indicate trail/sites where the scale was found.

curred less frequently, were inspected when detected. We allotted a searching time of approximately 2 minutes for each plant, particularly focusing on braches 2 cm thick or less. Infested plants were photographed and marked with GPS points. If scales were detected, a quick assessment on infestation was done. We estimated infestation level by judging the number of female scales in a 30 cm twig/branch, following the protocol developed by Pemberton 2003. Heavy infestation: > 100 scales in a 30-cm twig/branch, moderate infestation: between 10 and 100 scales in a 30-cm twig/branch, and light infestation: < 10 scales in 30-cm twig/branch. Samples collected were brought to the Hawaii Department of Agriculture for identification. The survey mainly focused on native host plants.

Results and Discussion

The scale was found in 13 out of the 17 survey sites (Tables 1 and 2). Among the botanical gardens surveyed, Hoomaluhia Botanical Garden had the highest level of infestation on native plants (Table 2). It is unclear why this site is experiencing high infestation levels. It is presumed that the scale established earlier at this site compared to other sites surveyed, and therefore the population had more time to build up. Other factors to consider are: well irrigated, fertilized plants and the close proximity of suitable hosts, as they provide ideal conditions for rapid colonization by LLS within botanicals gardens. This particular botanical garden is known to spray insecticides regularly against LLS. Frequent insecticide applications can lead to increased outbreaks of

pests, especially within urban landscapes (Raupp et al. 2001). Continuous exposure may stimulate hormoligosis, causing the pest to develop faster or produce more offspring (Guedes and Cutler 2014). Also, pesticide resistance may be another reason why this site exhibits high levels of infestation. However, these hypotheses need to be investigated in more detail. Queen Lilioukalani was the second most affected botanical garden. Both Waimea Valley and Koko Crater Botanical Garden had low to medium levels of infestation, primarily on Hibiscus spp. The low infestation level in Waimea and Koko Crater suggest that LLS was recently established at these sites compared to the other botanical gardens surveyed.

The scale was not detected at Makua Keaau forest reserve, Kealia Trail, Puu Ohia Trail, and Kolowalu Trail. The lack of presence of LLS at both Makua Keaau and Kealia Trail suggests that the scale has yet to reach these areas of northwest Oahu. However, more sites need to be surveyed along the Waianae mountain range to confirm its absence. The scale was not present within the native forest restoration area at the top of Puu Ohia (Tantalus) despite the number of suitable native plants in this restoration site. We suspect that the establishment of LLS may be affected by high levels of rainfall (Table 1). Both Kolowalu and Puu Ohia trails, receive an average annual rainfall of over 300 cm (Giambelluca et. al. 2013) (Table 1). Notably, all other surveyed locations receive less than 300 cm of annual rainfall (Table 1).

The survey also confirmed that the scale is not restricted to urban areas where it is already causing mortality, but it has spread far beyond the original detection site into natural areas and attacking native species. During the surveys, the scale was detected on 12 native species (Table 1). *Dodonea viscosa* and several native *Hibiscus* spp. were the most susceptible native hosts in botanical gardens (Fig. 3 A, B). Interestingly though, despite the abundant number of *D. viscosa* (a susceptible native species, according to this survey) present along the Lanipo trail, the scale was only detected at very low densities. This may suggest a recent establishment or that other unknown factors are influencing further proliferation. Future monitoring at this site may provide important insights regarding the progress of the infestation.

Although readily found on koa (*Acacia koa*) and ohia (*Metrosideros polymorpha*), the scale was present at very low numbers. The extent of any detrimental effect by LLS infestation on native flora has yet to be determined. However, we predict LLS population densities on native plants will continue to increase with the lack of control within natural areas. Identification of native host plants, as well as native habitats prone to invasion, is therefore crucial. At survey sites, the scale was readily found on non-native hosts such as fomosa koa (*A. confusa*), and christmas berry (*Shinus terebinthifolia*) at higher numbers (Table 3). Fomosa koa and Christmas berry are introduced species commonly found at lower elevations along many of the trail sites. The wide spread distribution of highly suitable non-native hosts may have provided an avenue for LLS to spread across the island.

A survey conducted in Florida detected LLS on 307 plant species in over 50 plant families (Howard et al. 2006). The families Anacardiaceae, Aquifoliaceae, Chrysobalanaceae, Myrsinaceae, Myrtaceae, Moraceae, Oxalisaceae, Rubiaceae, and Sapindaceae had representatives considered highly susceptible to LLS, based on dense populations of the scale consistently observed during surveys (Howard et al. 2006). Notably, of the native Hawaiian plants surveyed, species within the families Myrtaceae, Rubiaceae and Sapindace

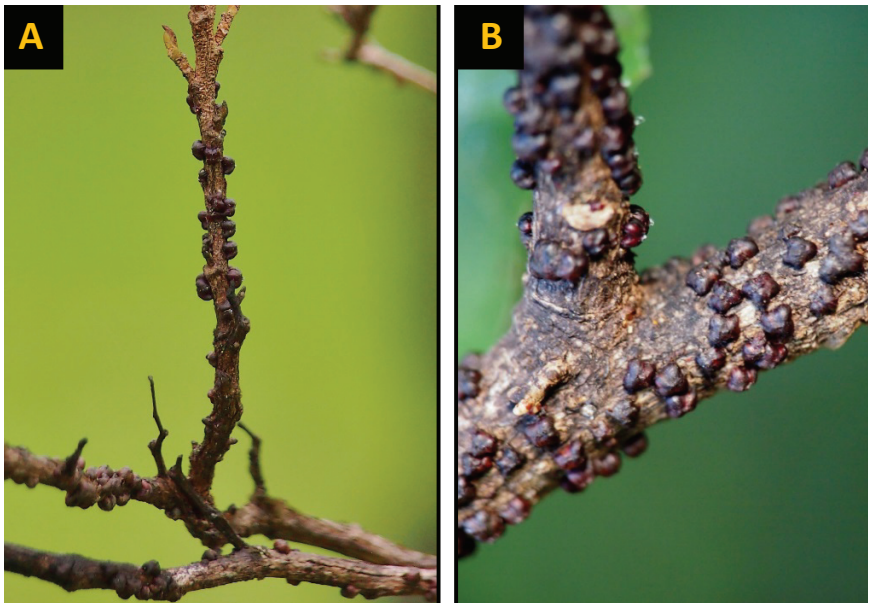

Figure 3. Lobate lac scale infestation found on various host plants. (A) High density of scales found on *Dodonaea viscosa*. (B) High density of LLS on *Hibiscus* spp.

show potential for high LLS susceptibility. Although low levels of infestation were typically observed in species within those families in forest systems, moderate to high infestations levels observed at botanical gardens perhaps infer future infestation problems. Those plant families have moderate to high numbers of native representatives. Other important families are Fabaceae and Malvaceae to which koa (*A. koa*) and *Hibiscus* spp. belong, respectively.

The fact that it takes the scale 4–5 months to complete a life cycle and that symptoms of branch dieback already existed at the time of its original detection, suggests the scale has been present on Oahu far before its first official report back in October 2012. Our data, and previous survey records from HDOA (unpublished data), now indicate the scale is found on 16 native species and over 99 non-native species (Tables 2 and 3). Although surveys in natural areas detected only low numbers of LLS (in most cases only one or a few scales were found per plant), it is unknown how the infestation will progress at these sites. Therefore, it is important to establish permanent plots for future systematic surveys.

The presence of LLS from Waimea Valley to Koko Crater Botanical Garden indicates the establishment of LLS along the Koolau range (Fig. 2). The spread of this pest and progress of infestation pose a significant threat to the structure and function of native ecosystems in Hawaii. Both non-native and native plants are extremely important in Hawaii's urban and native forests. Movement of infested host plants from one locality to the next is a key factor in spreading LLS between urban areas. The scale is currently restricted to Oahu, but given the frequency of interisland transport of goods and people, and the precedence of

Table 1. Geographical data and lobate lac scale presence or absence information for all trail/sites surveyed.

Trail/Site	Location	Site type	Area	Elevation (m)‡	Annual rainfall (cm)†‡	Presence or absence of LLS
Hoomaluhia BG	N21° 22.987' W157° 48.289'	Botanical Garden	Kaneohe	97	211	Present
Liliuokalani BG	N21° 19.206' W157° 51.340'	Botanical Garden	Nuuanu	46	99	Present
Koko Crater BG	N21° 17.167' W157° 40.904'	Botanical Garden	Hawaii Kai	119	75	Present
Waimea Valley	N21° 38.160' W158° 03.283'	Botanical Garden	Waimea	9	129	Present
Kuli'ouou Ridge Trail	N21° 18.477' W157° 43.357'	Kuli'ouou Forest Reserve	Kuli'ouou	229	141	Present
Lanipo Trail	N21° 18.632' W157° 46.498'	Honolulu Watershed Forest Reserve	Maunalani Hts	496	221	Present
Kolowalu Trail	N21° 19.368' W157° 47.293'	Honolulu Watershed Forest Reserve	Manoa	487	312	No LLS
Puu Ohia/Pauoa Flats Trail	N21° 20.297' W157° 48.717'	Honolulu Watershed Forest Reserve	Makiki	466	359	No LLS
Round Top Forest Reserve[1]	N21° 18.902' W157° 49.208'	Honolulu Watershed Forest Reserve	Makiki	265	171	Present
Kamanaiki Trail	N21° 21.588' W157° 50.021'	Honolulu Watershed Forest Reserve	Kalihi	504	276	Present
Moanalua Trail	N21° 22.982' W157° 51.468'	Honolulu Watershed Forest Reserve	Moanalua	199	295	Present
Aiea Loop Trail	N21° 24.121' W157° 53.043'	Keaiwa Heiau State Park	Aiea	439	263	Present
Waimano Valley Trail	N21° 25.274' W157° 56.691'	Ewa Forest Reserve	Pearl City	206	131	Present
Likeke Trail	N21° 22.248' W157° 47.213'	Kaneohe Forest Reserve	Nuuanu/Pali	210	209	Present
Maunawili	N21° 21.213' W157° 45.918'	Waimanalo Forest Reserve	Maunawili	92	187	Present
Kealia Trail	N21° 34.135' W158° 12.605'	Kuaokala Forest Reserve	Mokule'ia	357	97	No LLS
Makua Kea'au[1]	N21° 30.177' W158° 13.269'	Makua Keaau Forest Reserve	Makua Keaau	97	84	No LLS

† = Annual rainfall data referenced from 2011 Online Rainfall Atlas of Hawai'i (Giambelluca et. al., 2013). ‡ = Elevation and rainfall data determined from the last GPS location where LLS was found on each hiking trail. [1] = Forest reserve without trail

Scientific name	Family	Common name	Ho'omaluhia BG	Lili'uokalani BG	Moanalua Trail	Aiea Loop Trail	Puu Ohia/Pauoa Flatss Trail	Round Top Forest Reserve	Kolowalu Trail	Likeke Trail	Kamanaiki Trail	Lanipo Trail	Makua Kea'au	Maunawili	Waimea Valley	Kuli'ou'ou Ridge Trail	Waimano Valley Trail	Koko Crater BG	Kealia Trail
Abutilon menziesii	Malvaceae	Ko'oloa' ula (Red Ilima)																	
Acacia koa	Fabaceae	Koa	**L**		**L**	**L**					**L**	**L**		**L**			**L**	**L**	
Alyxia oliviformis	Apocynaceae	Maile																	
Caesalpinia kavaiensis*	Fabaceae	Uhiuhi													**L**				
Diospyros sandwicensis	Ebenaceae	Lama															**M**		
Dodonaea viscosa	Sapindaceae	A'ali'i	**H**	**M**								**L**			**L**			**L**	
Erythrina sandwicensis	Fabaceae	Wiliwili																	
Gardenia brighamii*	Rubiaceae	Nanu		**H**											**L**			**M**	
Hibiscus arnottianus spp.	Malvaceae	Various spp.													**M**			**M**	
Metrosideros polymorpha	Myrtaceae	Ohia	**M**		**L**	**L**					**L**						**L**		
Myoporum sandwicense	Myoporaceae	Naio																	
Nototrichium humile	Amaranthaceae	Kului																	
Osteomeles	Rosaceae	Ulei									**H**	**L**				**L**			
Pittosporum glabrum	Pittosporaceae†	Hoawa	**H**																
Psychotria hathewayi*	Rubiaceae	Waianae Wild Coffee	**H**																
Psydrax odorata*	Rubiaceae	Alahe'e	**H**																
Sapindus saponaria	Sapindaceae	Manele (Soapberry)	**H**																
Scaevola	Goodeniaceae	Naupaka																	
Sida fallax	Malvaceae	Ilima (Yellow)																	
Styphelia tameiameiae	Epacridaceae	Pukiawe																	
Wikstroemia oahuensis	Thymelaeaceae	Akia																	
Xylosma hawaiiense	Flacourtiaceae	Maua																	

H = Heavy infestation: > 100 scales on a 30 cm twig/branch. M = moderate infestation: between 10-100 scales on 30 cm twig/branch. L = light infestation: < 10 scales on 30 cm twig/branch.
* = Indicates new host record for Hawaii. † = Indicates plant family not recorded in Howard et al. *2006*

Table 2. The presence or absence and infestation level of lobate lac scale on various native Hawaiian plants surveyed along various trials and botanical gardens (BG) on the island of Oahu.

Table 3. The presence or absence and infestation level of lobate lac scale found on common non-native plants surveyed along various trials and botanical gardens (BG) on the island of Oahu.

Scientific name	Family	Common name	Ho'omaluhia BG	Lili'uokalani BG	Moanalua Trail	Aiea Loop Trail	Puu Ohia/Pauoa Flats Trail	Round Top Forest Reserve	Kolowalu Trail	Likeke Trail	Kamanaiki Trail	Lanipo Trail	Makua Kea'au	Maunawili	Waimea Valley	Kuli'ou'ou Ridge Trail	Waimano Valley	Koko Crater BG	Kealia Trail
*Acacia confusa**	Fabaceae	Formosa koa				**M**		**M**			**H**	**M**				**L**			
Aleurites moluccana	Euphorbiaceae	Kukui																	
*Eucalyptus spp.**	Myrtaceae	Eucalyptus									**L**								
Schinus terebinthifolia	Anacardiaceae	Christmas berry			**M**	**M**		**M**		**M**		**M**				**M**	**M**		
Psidium guajava	Myrtaceae	Common guava			**L**														
*Psidium cattleianum**	Myrtaceae	Strawberry guava			**L**												**L**		
Santalum spp.	Santalaceae	Iliahi (sandlewood)																	

H = Heavy infestation: > 100 scales on a 30 cm twig/branch. M = moderate infestation: between 10-100 scales on 30 cm twig/branch. L = light infestation: < 10 scales on 30 cm twig/branch.
* = Indicates new host record for Hawaii

pest range expansions, the spread to other Hawaiian Islands is highly probable. Strict regulation for trading plants interisland is also extremely important to ensure that this invasive species does not establish on other islands. Immediate efforts are needed in both alerting and educating local plant nurseries (especially distributors) of LLS and the proper means of control (mechanical removal or application of systemic insecticide). This will reduce the probability of LLS spreading across the neighbor islands.

One of the objectives of this survey was to determine the current distribution of this invasive species in native forests in Hawaii and to determine the need for management actions. Although the scale was found at many natural forests, it was not causing severe damage at these sites. Nevertheless, several natural areas throughout Oahu were not included in the survey. In order to determine the current distribution of the scale, more surveys are needed. Continued monitoring of selected sites will help assess the progress and severity of the infestation, and determine the need for timely actions in the future. Since moderate to high infestation levels were observed at botanical gardens and along a few trails, systematic surveys may also help detect any already existing natural enemies associated with lobate lac scale. If present, natural enemies could potentially be reared and used in an augmentive biological control program to suppress the spread LLS in native forest areas on Oahu.

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