# BLACK SCALE CONTROL PROGRAMS AND CARBARYL ALTERNATIVES

Houston Wilson
Asst. Cooperative Extension Specialist
Dept. Entomology, UC Riverside

Kent Daane
Cooperative Extension Specialist
Dept. Environmental Science, Policy and Management, UC Berkeley

## 1. Overview and History of Black Scale

### 1.1 Geography – native range, timeline of introduction to California

Black scale (Hemiptera: Coccidae: *Saissetia oleae*) is a soft scale insect native to South Africa (De Lotto 1976). This species is globally distributed; it was likely introduced to California in the late 1800s and has since become an economic pest primarily on olive, citrus and ornamental plants. It has also been reported on many other agricultural hosts including almond, fig, grape, and pistachio as well as many non-crop hosts such as oleander (UC IPM 2014), although species identification of soft scale insects is often incorrect.

### 1.2 Biology and ecology – development requirements

Black scale adults are small (0.2 inches diameter) and dark brown or black. Females can lay up to 2,500 eggs (Tena et al. 2007), which they protect beneath their body until crawlers emerge. Crawlers are lighter in color (yellow to orange) and spend a few days distributing themselves across the leaves and branches in search of an optimal feeding site (Argyriou 1963). Once settled, it inserts its mouthpart into the plant and begins to feed. The immature scales then pass through three instars (i.e. immature stages) that develop a distinguishing "H" pattern on their dorsum before molting into a sexually immature adult (i.e. rubber stage) and then sexually mature adult. Reproduction is largely parthenogenic (i.e. no mating), and while males have been reported, they are rarely found in California.

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| Black scale eggs and crawlers leaving the adult carapace. | Black scale second and third instars. | Black scale adults and partial defoliation and mold damage. |

In California olives, especially those found in the interior valleys, black scale overwinter in various stages of immature development (but not as crawlers), typically as second and third instars (Daane and Caltagirone 1989). As the temperatures warm in spring there is a rapid growth of the scale – to the rubber stage and mature adult stages that then begin to produce eggs. Crawlers typically appear in late spring or early summer.

Black scale has either one or two generations per year depending on climate and host plant (Mineo and Sinacori 1976, Podoler et al. 1979, Neuenschwander and Paraskakis 1980). In California, in cooler coastal regions it has two generations per year, whereas in warmer inland regions it experiences only one generation per year, although a partial second generation can sometimes be found, especially in trees with dense canopies that provide a cooler microclimate (Daane and Caltagirone 1989, Tena et al. 2007, UC IPM 2014, De Souza et al. 2015).

## 2. Agriculture Importance

### 2.1 Damage to key crops

Black scale is a pierce-suck feeder that excretes large amounts of honeydew onto the tree, which serves as a substrate for the development of sooty mold. Black scale infestations on olive will reduce tree vigor, productivity, and can impact bloom in the following year. The most damage is caused during the spring to summer period of rapid scale growth, which leads to more honeydew excretion and sooty mold accumulation – often causing leaf drop.

## 3. Control strategies

### 3.1 Cultural/mechanical

Scale outbreaks have been linked to temperature and relative humidity in the olive orchard. In the Central Valley, crawlers typically hatch in May and June and are immediately subjected to hot, dry summer conditions. The greatest mortality of the early instars occurs at this time (Peleg 1965, Rosen et al. 1971, Podoler et al. 1979, Roberti 1980). Even a brief period of hot weather can significantly reduce scale populations. In Crete, a Scirocco storm (i.e. hot winds) from the African deserts caused a 20-fold reduction in numbers, by March the population was 0.3% of its original size (Neuenschwander and Paraskakis 1980).

In California, a study of olive cultural practices demonstrated that pruning for a more open canopy, thereby increasing temperatures, could lead to increased mortality (Daane and Caltagirone 1989). This work demonstrated that as much as 90% of the crawlers and second instars can die from this abiotic mortality between May and July, when temperatures are hot and dry. As such, combinations of mild spring and summer temperatures, along with closed canopies that reduce temperatures can result in small black scale populations quickly increasing in numbers.

Similarly, in Europe and Israel, researchers noted that cultural practices that affected the microclimate can influence black scale development, survival and natural enemy impact (Rosen et al. 1971, Paraskakis et al. 1980). For example, in Italy researchers report that closed canopies and high-volume sprinkler systems will lower ambient temperature and raise humidity, producing an environment more conducive to black scale outbreaks, whereas hot, dry conditions increased scale mortality (Roberti 1980). More recent work has demonstrated that a combination of open canopy and insecticide applications (fenthion) can provide effective control (Ouguas and Chemseddine 2011). Overly vigorous trees or trees with increased irrigation levels may contribute to development of black scale populations (Rosen et al. 1971).

In most olive growing regions, crawler mortality resulting from hot, dry temperatures and host plant condition are critical factors for natural control (Stratopoulou and Kapatos 1998). Unlike most of Europe and the Middle East, California irrigates their orchards for higher per tree production, which also leads to more tree vigor compared to traditional dry-farmed orchards in Europe. In the mid-1990s, however, super high-density (SHD) olive production systems were developed in Spain, and in the early 2000s these were adopted to California conditions for the production of olive oil, which until that point had been relatively limited. These systems rely on mechanical pruning to produce a "hedge" style of production, which is beneficial to production in many respects but does result in a more closed canopy that likely promotes black scale outbreaks.

**3.2 Biological Controls**

Black scale is exotic to most olive growing regions and has been the target of numerous classical biological control programs (Bartlett 1978). In California, black scale was the focus of one of the largest biological control programs ever conducted. To comprehend this, we have to understand the circumstances of California agriculture in the early 1900s and the excitement for classical biological control at that time. The cottony cushion scale (Hemiptera: Monophlebidae: *Icerya purchase*) had recently been controlled in citrus by the importation of the vedalia beetle (Coleoptera: Coccinellidae: *Rodolia cardinalis*) from Australia (Caltagirone and Doutt 1989). The knock-out success of this classical biological control program had led to many subsequent, and somewhat indiscriminate, releases of additional coccinellids, often described as the “ladybird fantasy” period (Caltagirone and Doutt 1989). At that time, California citrus and olives shared numerous traits, including black scale as one of the more serious pests. For this reason, a large biological control program was launched in California in the early 1900s against black scale in citrus and olives. While importation of natural enemies had worked so well for cottony cushion scale, black scale would prove to be more challenging.

An initial exploration for natural enemies of black scale was made in 1891 to Australia, before researchers understood the origin of the pest. More intense explorations were made between 1915-1940, especially to Africa, the presumptive native region of black scale and its close relatives (reviewed in Smith 1921, Compere 1939a, 1939b, Bartlett 1978). Efforts to discover and import an effective natural enemy for black scale continued during most of the 20th century, with sporadic starts and stops based on newly developed insecticides from the 1940-60s (see insecticide section). Bartlett (1978) reviewed biological control efforts up to the 1970s, listing about 40 species of small wasps (in the families Encyrtidae, Aphelinidae, and Pteromalidae) and 10 species of lady beetles imported and released for black scale control in California and Florida. The last importation attempts were from 1976-1982, when five parasitoid species were imported to California from South Africa (*Prococcophagus saissetiae*, *P. probus*, *Coccophagus rusti*, *Aloencyrtus saissetiae*, and *Metaphycus inviscus*) and in 1985 from Spain with one wasp imported (*M. hageni*) (Kennett 1986, Daane et al. 1991, 2000). Out of these latter six parasitoid species, only *P. probus*, *C. rusti*, and *M. hageni* became established in Central Valley olive orchards. While this was a much higher percentage of establishment compared with previous attempts to introduce black scale parasitoids, these species are still relatively low in abundance and not very commonly found.

Why were so many of the initial attempts to establish parasites unsuccessful? Many failed because of poor parasite taxonomy, inadequate biological information, and/or faulty release methods. For example, until the 1930's many primary parasites with obligatory male hyperparasitic habits were discarded as dangerous secondaries (Compere 1925, Flanders 1936). Often only a few, or a few hundred, or an unknown number of parasites were released. Many others were ill-suited to the climate in California's interior valleys. Poor methodology was not the only reason many natural enemies did not become established. Host-parasite racial differences may influence parasite adaptation and establishment (Bartlett 1960). There were also questions about parasitoid taxonomy, which may have led some researchers to discount some parasitoid populations. For example, in the 1970s, French researchers suggested there were enough physiological and behavioral differences in ‘biotypes’ of *Metaphycus lounsburyi* from Spain, Italy, and California that that they could all be simultaneously used in the same orchard for biological control (Panis and Marro 1978). Later, Daane and Caltagirone (1999) showed that the ‘*M. lounsburyi*’ in California and Spain represented two species, naming the new species as *Metaphycus hageni*. It is then possible that a parasite species previously imported to California that failed to establish may have other biotypes, with different physiological or behavioral attributes, that would do well under the environmental conditions of the Central Valley.

How well do natural enemies regulate black scale in California? Surveys of black scale parasitism in California were conducted in the 1970s and 1980s in Central Valley olives (Kennett 1986, Daane et al. 1991) and southern California citrus and olives (Lampson and Morse 1992). Most of these studies agree that the three most common parasitoids are *Metaphycus lounsburyi*, *Metaphycus helvolus*, and *Scutellista caerulea*, which account for about 80% of the species reared from black scale (see photos). They have gone through a number of name changes such that only *M. helvolus* has the same name as when it was first imported into the United States! For example, *M. lounsburyi* is a valid name for the species up to now called *Metaphycus bartletti* (*M. bartletti* is no longer a valid name) and what had been previously thought to be a single species (and referred to as *M. lounsburyi*), is actually a mix of two species: *M. hageni* and *M. anneckei* (Daane et al. 2000). Moreover, *S. caerulea* (= *S. cyanea*) is commonly referred to as a parasitoid, but might be better described as a predator because the adult female parasitoid places an egg underneath a mature scale, where the resulting parasitoid larva feeds on the deposited eggs of the black scale (Ehler 1989).

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| *Metaphycus lounsburyi* attacking a third instar or 'rubber-stage' black scale. | *Metaphycus helvolus* attacking a second instar black scale. | *Scutellista caerulea* placing an egg 'under' a third instar black scale. |

*Metaphycus lounsburyi* (= *bartletti*) was introduced to California in 1958, has since spread throughout the state, and in unsprayed fields parasitizes a large percentage of pre-ovipositional and adult scale (Kennett 1980). *Metaphycus helvolus* was introduced in 1937 when the focus of the biological control program was black scale on citrus in southern California (Flanders 1942, Smith et al. 1945) and was reported to reduce scale incidence by 85-90%, with major infestations almost entirely confined to the interior valleys (Smith et al. 1945). *Scutellista caerulea* was one of the first natural enemies introduced, imported from South Africa and release first in Louisiana and Florida in 1898 against other soft scale species (Plank and Catchings 1923) and later (1901-1902) released in California (Smith 1921). In some California orchards, these three species combined can provide adequate suppression of black scale (Kennett et al. 1965). Similarly, studies in Greece, Italy, and Libya have attributed significant black scale mortality to natural enemy activity, primarily *M. helvolus*, *M. lounsburyi*, *M. anneckei*, and *M. hageni* (Viggiani et al. 1975, Argyriou and Katsoyannos 1976, Monaco 1976, Neuenschwander and Paraskakis 1980, Paraskakis et al. 1980, Viggiani and Mazzone 1981).

From the following it would seem that biological control should suppress black scale in California orchards. One of the obvious problems is the use of pesticides that kill these natural enemies. Earlier work with GF-120 and black scale honeydew suggested this application was relatively safe for different natural enemy species (Nadel et al. 2007, Wang et al. 2011). However, the carbaryl applications for black scale would reduce natural enemy populations, whereas an oil-only spray is less likely to cause damage to the natural enemies. Another problem is that ants tending the scale reduce rates of parasitism and the common control for ants is an application of carbaryl. Black scale on citrus and olives is one of the classic examples of ant interference, first described by Flanders (Flanders 1943) and Bartlett (Bartlett 1961) and experimentally verified by Barzman and Daane (Barzman and Daane 2001).

Another problem is the 'univoltine' development of the scale population found in most interior valley orchards. Daane and Caltagirone (1989) report a univoltine and more synchronous development pattern (e.g., 1st and 2nd, then months later 2nd and 3rd rather than all stages present) in the interior valley than in coastal locations, which does not favor parasitoid establishment. Cultural practices typically used, especially pruning, may exacerbate climatic mortality but can also promote a more synchronous scale population. This impacts parasitism because *M. helvolus* attacks 2nd and 3rd instars, *M. lounsburyi* attacks 3rd instar and rubber stage scale, and *S. caerulea* attacks rubber stage and adult scale. When these stages are not present for long periods during the season because of the synchronous development pattern, then the parasitoids must survive as adults for long periods of time without any hosts. It is, therefore, not surprising that more parasitoids are found in olive orchards that create two microclimates – a hot, dry region higher in the canopy and a cooler, more humid region lower in the canopy – as is found in orchards with tall, older trees and sprinkler irrigation but rarely found in orchards with hedge pruning.

### 3.3 Chemical controls

Historically, all of the infamously harsh chemicals were used to control black scale on citrus and olives in the early 1900s, such as fumigation with hydrocyanic acid gas (Quayle and Rust 1911, Quayle 1915). Resistance soon followed (Quayle 1938), leading to the use of different insecticides, including early enthusiasm for DDT and the organophosphate parathion to control black scale and red scale on citrus (Stafford and Hinkley 1946, Stafford and Hoffman 1948). The attempted control of these two scale pests was documented in the book "To Make a Spotless Orange" by Richard Sawyer. Other materials included oils and calcium cyanide dusting in the 1930s (Boyce et al. 1940, Kirkpatrick 1941), cyanide fumigation in the 1940s (McGregor 1942), and combinations of insecticides (parathion and malathion) and oils in the 1950s (Chessman 1957).

Today, most olive growers use relatively modern tools for control of olive fruit fly (Tephritidae: *Bactrocera oleae*, OFF) – the most commonly applied insecticide in olives is Spinosad (GF-120), which is put onto about 75% of the total acreage annually, usually in July or August. Another chemical recommended for OFF is fenpropathrin, which has been steadily increasing in use over the past 10 years (DPR-PUR 2017).

However, for black scale control, insecticides (carbaryl) and oils are still used, typically applied in combination in August, with a follow-up application of oils in November if needed. These applications of oil/carbaryl are made to about 30% of the California olive acreage annually (DPR-PUR 2017). However, the disruptive effects of this program on black scale natural enemies has long been noted (Orphanidis and Soultanopoulos 1962, 1964); basically, it is difficult to establish biological controls for black scale when applying the standard pesticide program against this pest.

## 4. Regulatory Context for Key Chemical Controls

### 4.1 Market summary

California accounts for more than 99% of olive production in the United States. There are currently about 56,000 total acres in production, with about 40,000 acres destined for olive oil and the other 16,000 acres for table olives (CDFA 2018a). Over the past 10 years (2008-2018), total olive yield has risen from approximately 97,000 tons/year to around 157,000 tons/year. This is due to an increase in acreage (30,000 - 36,000 acres) along with increased yield/acre (2.8 - 4.3 tons/acre) with the adoption of super high-density plantings for oil production (CDFA 2018a).

About 40% of the California olive crop is exported, representing $40 million in export value. Most exports currently go to Canada (37%), Mexico (14%) and the EU (10%), followed by Japan (7%), Taiwan (5%) and a mix of other destinations (27%) (CDFA 2018b).

While carbaryl can be effective for the control of black scale, it is also toxic to numerous non-target organisms, including honey bees and key beneficial insects, and may be subject to federal and/or state regulation in the near future (Rubin 2014, Zeiss 2015, DPR 2016).

Given that 40% of the California olive crop is exported, minimum restricted levels (MRLs) in key export markets will be important when considering the continued use of carbaryl or the adoption of alternatives. Table 1 summarizes MRLs in the US and key export markets for dominant active ingredients (AIs) currently used in olives along with proposed alternatives. While carbaryl MRLs are unified across the United States, Mexico and Canada, more stringent restrictions have been placed on this AI in the EU and Taiwan.

Table 1. MRLs (ppm) of key AIs for current or potential control of black scale. Data is presented as allowable ppm for “table olives / olive oil”. Source: Global MRL Database (2018)

| Country | Carbaryl | Spinosad | Fenpropathrin | Buprofezin | Pyriproxyfen |
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| United States | 10 / - | 0.02 / - | 5 / - | 3.5 / 4.8 | 1 /2 |
| Canada | 10 / - | 0.1 / - | 5 / - | 5 / - | 1.5 / 2 |
| Mexico | 10 / - | 0.002 / 0 | 5 / - | 3.5 / 4.8 | 1 / 2 |
| European Union | 0.01 / 0.02 | 0.02 / 0.02 | 0.01 / 0.01 | 5 / 5 | 0.05 / 0.05 |
| Japan | 30 / 25 | 0.3 / - | 5 / - | 5 / - | 1 / - |
| Taiwan | 0.5 / - | 0.01 / - | 0.01 / - | 1 / - | 0.01 / - |

## 5. Carbaryl Alternatives

### 5.1 Efficacy studies

Some alternatives to carbaryl for control of black scale could include newer AIs that are commonly used for more sustainable control of scale insects in other cropping systems. This includes insect growth regulators such as pyriproxyfen and buprofezin or systemic products like spirotetramat or the neonicotinoids imidacloprid and acetamiprid. Some additional novel AIs that may be worth consideration include tolfenpyrad, sulfloxaflor, and flupyradifurone. In the EU, where carbaryl use is heavily restricted, current recommendations for black scale control on olive emphasize cultural practices along with the use of oils and insect growth regulators, pyriproxyfen in particular (Mansour et al. 2017, EU Commission 2019, Junta de Andalucia 2019). While there is no black scale efficacy data for any of these alternative AIs, recent studies have demonstrated their impact on other scale pests (e.g. San Jose scale, California red scale, European fruit lecanium) in perennial crops (Walston et al. 2004, Grafton-Cardwell et al. 2006, Beers and Talley 2007, Grafton-Cardwell and Scott 2011, Hahn et al. 2011, Reissig and Combs 2011, Van Steenwyk et al. 2016).

### 5.2 Regulatory aspects of novel products

While one potential alternative AI pyriproxyfen is also more regulated in the EU and Taiwan, tolerance levels for buprofezin are either equivalent or even higher than domestic standards in Canada, Mexico, EU and Japan. Only in Taiwan is buprofezin more restricted than in the US. MRLs on olive have not been established for tolfenpyrad, sulfloxaflor, and flupyradifurone or any of the systemic products (imidacloprid, acetamiprid, spirotetramat).

## 6. Conclusions

As detailed, black scale has been the target of numerous control programs, with a great effort made to establish natural enemies to provide biological control. Many of these natural enemies have established and are still present in California, albeit in low numbers. Their impact is lowered by the use of some types of insecticides and by the univoltine development of the scale in warmer interior regions, which is heightened by modern cultural practices of hedgerow pruning.

Current needs are then to test and develop additional insecticide controls that might promote, or at least will not lower, natural enemy activity. Basically, the same insecticide program used in the 1940s (parathion and oil) is being used today (carbaryl and oil). There are numerous other materials that may be effective, and their addition to the growers' arsenal has the added benefit of lessening any potential for resistance development and lower the PUR index of annual carbaryl use in olives, which may in turn prolong its registration. Furthermore, it will be important to understand how the relatively new hedge style of production influences black scale population development and the penetration of these alternative AIs.

Additional research needs may include the basic understanding of black scale races or sibling species. As mentioned, soft scales are difficult to properly identify and there are a number of soft scales in California that look similar, including the 'Mexican black scale' (Dean and Hart 1972) and earlier researchers had noted that biotype differences in black scale might influence parasitism (Bartlett 1960). This would be mostly an academic study but could explain why earlier reports of biological control in southern California citrus were so promising, as well as why black scale is only an occasional pest of citrus in the Central Valley.

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