Battling the Beetles: Insect Growth Regulators as a Tool for Pest Management

Abstract

Conservators and collections managers at the Natural History Museum had been battling an infestation of drugstore beetles (*Stegobium paniceum*) within the Birds and Mammals collections for a number of years without success. Despite diligent freezing of infested specimens, the large size of the collections (over 200,000 specimens) meant that, in many cases, previously frozen specimens became reinfested before the freezing of the rest of the collections had been completed.

We realized that we needed to add some new weapons to our arsenal in order to win our battle with the beetles. While continuing to follow a proactive pest management approach, including cleaning, eliminating clutter, freezing infested or potentially infested specimens, and monitoring the collection areas to identify specific areas of infestation, we also decided to try a species-appropriate insect growth regulator (IGR) and other safe pest control products. We did not expect any one of these approaches to be effective on its own, but hoped that in combination, they would slow the spread of the beetles long enough for us to make headway with targeted freezing treatments.

After more than a year following this approach, our results remained mixed. Questions about whether the insect growth regulator was having any effect on the beetles drove us to test two other insect growth regulator products using a different delivery system. Based on our testing, we implemented a new treatment regime using a different insect growth regulator with a delivery system intended to give the beetles a greater exposure to the insect growth regulator.

Drugstore Beetle Fun Facts:

- Drugstore beetles (*Stegobium paniceum*) are so-named because of their ability to thrive on just about anything, even herbal medicines and pharmaceuticals. (Edde, et al. 2012)
- Drugstore beetles show a preference for chocolate and are known to infest cocoa factories. (Hill 1990)
- Drugstore beetles are one of the few insects for which metal-eating behavior has been documented. (Jones 1997)
- Drugstore beetles can thrive in environments ranging from 15–35°C and 30–100 % relative humidity. Moreover, different sets of conditions within these ranges produce different optimal qualities in the beetles, such as rapid development, heavy adults, high rates of survival to adulthood, and overall longevity, demonstrating their adaptability and persistence as a species. (Lefkovitch 1967)

Background

The Birds and Mammals collections are stored in the same collection range not for taxonomic reasons obviously, but because the specimens are prepared in a similar way: the skins are removed, cleaned, dried, and stuffed over a cotton wool and stick form. Skeletons are stored in boxes. Although the skins are cleaned, they remain attractive to insects.

The drugstore beetle infestation in the Birds and Mammals Collection was first discovered in 2003. The beetles may have been brought in on a specimen that returned from a research loan or may have gotten into the collection from the attic or ductwork. Since the serious nature of the infestation was discovered, the collection managers have been systematically freezing infested specimens, as well as any specimens going in or out of the collection.

Unfortunately, there are a number of reasons why the infestation spread despite efforts to control it:

1. The size of the collection: There are 213,000 specimens in the Birds and Mammals collections, housed in over 500 cabinets. And there are only 8,760 hours in a year, even if you work 24/7. To illustrate the scale of the problem, the first round of systematic freezing for the entire Ornithology collection took five years.
2. The poor seal of the cabinets: Many cases have deteriorated gaskets which are difficult to remove and replace. Specimens can become reinfested and the infestation can spread.
3. The age of the compactor system: The compactor system is old and would very likely break down if disassembled for the mass-freezing of all the cabinets.
4. A loophole in the freezing program: The cabinets themselves are not actually frozen, just vacuumed. It is possible that beetle eggs could remain.
5. Limited staff capacity: There is one collection manager of Birds and one of Mammals, and at most, two conservators.
6. Inadequate climate control: maintaining cooler temperatures and lower relative humidity would curb spread of infestation.
7. Proximity to public galleries: The collection range cannot be fumigated because the museum is open to the public nearly every day of the year and the range cannot be completely isolated from the adjacent public galleries.
8. Difficulty in spotting active infestation: The larvae that are actively eating the specimens generally settle on interior surfaces or deep within the fur or feathers and are almost never visible. We mainly see the adult beetles after they emerge, that is, after they have already laid their eggs on a specimen and are nearing the end of their life cycle.

Since the onset of the infestation, efforts to control this problem have included repairing gaps in ducts and crawlspaces, installing door sweeps, monitoring with ultraviolet light traps and pheromone lure traps, applying

pesticides (by the facilities pest control contractor), cleaning cabinets and wiping down with a safe orange oil pest control product, replacing damaged gaskets in cases, maintaining low temperatures in the collection range, and systematically inspecting and freezing specimens.

With these efforts failing, we needed to incorporate additional pest control measures to buy ourselves enough time to work our way through freezing the infested specimens.

First, we renewed our efforts with the essential pest management approaches:

- Sealing windows and doors in the collection areas
- New climate control system that would be adequate for the space
- Cleaning and eliminating clutter to remove debris that could harbor infestation and to make hotspots of infestation easier to identify
- Freezing infested or potentially infested specimens
- Monitoring the collection areas to identify specific areas of infestation

Then, at the recommendation of pest control consultants (Kelly 2013, Choe 2014), we started a program incorporating two new weapons:

- Species-appropriate insect growth regulator (Gentrol® PointSource™ containing the insect growth regulator s-hydroprene)
- Pyrethrum silica gel desiccant dust (Drione®) (Baur 1990)

It was essential for us to choose relatively safe chemical pest control treatments that would not affect the specimens. While we did not expect any one of these approaches to be effective on its own, we hoped that in combination, they would slow the spread of the beetles long enough for us to make headway with targeted freezing treatments.

We initially projected that the program would take place over eighteen months and would require at least three rounds of the insect growth regulator to take into account the varying life cycle of the beetles.

Insect growth regulators were first developed in the 1960s, but have become even further advanced in the past decade with the growing awareness of the need for safer pest control approaches. Insect growth regulators work by mimicking or interfering with the hormones produced by the targeted group of insects during their different life stages and disrupting their development at critical points, like molting and pupation. A major benefit of insect growth regulators is their innocuous effect on life forms that do not rely on an exoskeleton.

So although they may affect other life stages, insect growth regulators kill insects primarily in the larval and pupal stages. The molting process in insects is controlled by hormones. The two major hormones involved in insect molting are ecdysone, which induces molting, and juvenile hormone, which, if present, determines that the insect will molt into a juvenile form. In fact, larvae generally go through several successive juvenile forms called instars. If the juvenile hormone is absent, the insect molts into a pupa or adult.

Because insect growth regulators work by interfering with the insect's molting process, they generally take longer to kill than traditional insecticides. How much time they take depends on the product, the target insect, and its life stage at the time of application. The three major categories of insect growth regulators and their mode of action are as follows:

- Juvenile hormone analogs or mimics cause premature molting of young immature stages, disrupting normal larval development.
- Chitin synthesis inhibitors disrupt molting by blocking the formation of chitin, the building block of an insect's exoskeleton.
- Ecdysone inhibitors block the molting hormone and break the life cycle at all larval stages.

Are there drawbacks to using insect growth regulators?

- Different IGRs target different insects, although most IGRs will have a detrimental effect on juvenile forms of any insect. It is important to identify the insect pest and select the appropriate IGR.
- IGRs are not immediately effective at stopping an infestation since they generally only affect larval or pupal stages.
- IGRs need to be used in sequence with "adulticides," to limit the spread of infestation from insects in later, reproductive life stages. (Tunaz and Uygun 2004)

We selected the Gentrol PointSource because it targets stored food product pests, like cockroaches, moths, and beetles, including drugstore beetles, and because it comes in an easy-to-use unit. It is considered safe to use around people, even in day care centers, hospitals, and food-handling establishments. It is no longer regulated to restrict use of this product to licensed pest control professionals only. And because the Gentrol targets a particular group of insects, is not toxic to other life forms, and breaks down fairly rapidly with exposure to sunlight, it is on the whole an environmentally-friendly choice.

S-Hydroprene, the insect growth regulator in Gentrol, is a juvenile hormone mimic; it kills larvae in the pupal stage, although it may also affect insects in the adult stage, often preventing them from reproducing. Gentrol was primarily tested for use on cockroaches, so its performance on drugstore beetles may not be as predictable.

The Gentrol is supposed to be effective for three months, after which, it must be replaced. Since the life cycle of the drugstore beetle can vary widely, several applications of Gentrol would be necessary.

The Drione dust does contain a pesticide, pyrethrum, which would potentially affect all life-stages of the insect with sufficient exposure. Pyrethrum is a plant-derived pesticide; it is one of the less hazardous pesticides in common use and it dissipates naturally after about six months.

Even after the pesticide is no longer effective, the silica gel desiccant dust may inhibit infestation by eroding the waxy cuticle of the insects and causing them to die of dehydration.

By using the dust at the base and door of the cases, we hoped to prevent spreading and re-infestation. This type of desiccating pesticide dust is not intended to be broadcast over wide areas; it is most effective for hard to reach places like the spaces between and behind cabinets, where specimen debris may accumulate and harbor pests. (Baur 1990)

The inspection of the cases and application of the insect growth regulator and pesticide dust require a team of at least two or three people. The protocol used is as follows:

- Cases are inspected. The bottom drawers are removed to allow inspection and cleaning. The beetles seem to accumulate in the bottoms of the cases, probably because of gravity. The beetles are attracted by light and head for the case door when they reach their adult phase. Some must lay their eggs on the original food source, and then just emerge at the end of their life cycle; others must emerge in search of new food sources on which to lay their eggs.
- All insect debris is vacuumed out of the case to allow detection of new or active infestation.
- Sticky blunder traps are placed in each case. We tried to select "likely locations" near the lower, front parts of the cases, but wanted to avoid placing the traps too close to specimens, which might become stuck in the traps and damaged. These traps are purely for monitoring purposes. Unfortunately, there are no guarantees that the beetles will wander into the traps, and in many cases, an empty trap gives a false negative.
- If signs of infestation are noted, an insect growth regulator unit is adhered to the inside of the case door. The Gentrol becomes airborne and disperses throughout the case. We placed the unit near the top of the case because the hydroprene is heavier than air. We found so many infested cases in the Mammals collection that we had to treat nearly every case (176 out of 182 mammals cases, compared to 138 out of 343 bird cases).
- The pesticide dust is applied to the bottom of the case as a barrier against beetles that are trying to get out – or in – to the cases. And also to the areas behind the cabinets which are difficult to clean and monitor.

Mid-Project Results

After the eighth month of our campaign and in some areas, the third round of Gentrol, we evaluated our results. We were not as far along as initially planned because, as mentioned above, we unfortunately discovered many more infested cases in the Mammals section; nearly all had some sign of past or present infestation, so that we had to treat nearly every case.

Did we see a reduction in the beetle population? Initially yes, perhaps because of our aggressive cleaning efforts; then disappointingly, no, not during the second round of Gentrol.

Entering into the third round of Gentrol gave mixed results; some cases where we had identified active infestation that had not yet been frozen showed few or no beetles. Discouragingly, some cases that had been repeatedly treated with Gentrol still had live beetles, indicating an active, ongoing problem. Most of the beetles appeared at the base of the case door, but it was unclear whether they had been trying to get in or out.

Our new climate control system was completed at the end of June, 2014, and we held out hope that cooler temperatures would also work in our favor to slow the reproduction of the beetles.

Even at this point in the project, it had become clear that the insect growth regulator was not the miracle cure we had anticipated. We realized that a number of factors could have been preventing the insect growth regulators from having the desired effect on the beetle problem. (Table 1)

Evaluation of initial results

Our lack of overwhelming success after our second and even third rounds of Gentrol application led us to question our approach: Was s-hydroprene the right choice of insect growth regulator for drugstore beetles? Although they are listed as target pests, there is a dearth of industry research specifically concerning the use of this insect growth regulator against drugstore beetles.

Does the s-hydroprene in the Gentrol PointSource applicator dissipate adequately throughout the case? Perhaps the limited air circulation within the case does not distribute the s-hydroprene evenly throughout every specimen drawer, since the unit is attached to the top of the inside of the door.

S-hydroprene has a relatively low vapor pressure of 1.88×10^{-4} mm Hg (at 25° C). Environmental studies were inconclusive about the extent to which it remained airborne if used in shipping containers. (Health & Safety Executive, Biocides & Pesticides Assessment Unit 1996) The s-hydroprene might dissipate too quickly to reach lethal exposure if cases are opened for research.

In addition, drugstore beetle larvae likely embed themselves inside the prepared specimen skin, where they may be insulated against lethal exposure to any airborne s-hydroprene. Advice from urban entomology researchers and extrapolation from related research indicated that greater exposure would yield better results. (Choe 2014, Gilberg and Roach 1997)

Could other insect growth regulators or delivery systems improve our results? We decided to conduct a test to find out.

Table 1 Variables and their potential effect on the beetle infestation

Factor	Description	Pro	Con
Drugstore beetle life cycle	Life cycle may vary from 2-7 months; larval stage may last 1-5 months. Life cycle is affected by temperature and humidity. (Hill 1990)	Long larval stage may mean more opportunities for effective exposure.	Variable life cycle may mean missing ideal timeframe for exposure. Long larval period may forestall lethal effect. (Tunaz and Uygun 2004)
Specimen preparation	Some specimens may have been incompletely cleaned during preparation, e.g., hummingbirds, which are essentially desiccated.		More edible material may make these specimens more attractive to infestation.
	Older specimens may have been prepared using arsenic.	Cases with older specimens seem to be less frequently infested.	
Frequency of access	Some cases are opened frequently to access specimens for research or add new specimens.	Infestations are more likely to be discovered if cases are checked frequently.	Gentrol may dissipate quickly if case is opened frequently. Adding new specimens and opening case door may increase likelihood of infestation
	Some cases are rarely opened, especially if new specimens are not being collected.	Gentrol may reach lethal concentration if cases are not opened. Older specimens may have some protection from pesticide preparation. Infrequently opened cases may have a better seal to prevent insects from entering	Infestation may go undetected if cases are checked infrequently.
Proximity to windows	Adult beetles are attracted to light.	Beetles may be drawn to windows instead of spreading to other cases.	Cases near windows may be more in the path of beetles ready to spread out and reproduce. Beetles that end up dead on windowsills have probably already laid eggs inside a case.

Comparison of alternative insect growth regulators

The alternative insect growth regulators were selected for comparison based on the appropriateness of their labeled use and target insects, their relative vapor pressures, their relative safety, and their widespread use in the pest control sector. (Table 2)

To give some context to these products, s-methoprene and pyriproxifen are the insect growth regulator components in two commonly-used flea control products intended for direct application to cats and dogs, such as Frontline® and Advantage®.

For our initial test, the insect growth regulator pyriproxyfen was eliminated as a candidate because its vapor pressure was much lower than that of s-hydroprene and s-methoprene, which are already very low compared to their carrier solvent, petroleum distillates. To be effective within the specimen case, the product would need to work by dispersal through space and not just direct physical contact, so some volatility was desirable. Note that all of these insect growth regulators functioned as juvenile hormone mimics. (Health & Safety Executive, Biocides & Pesticides Assessment Unit 1996, Csondes 2004, Sullivan 2000)

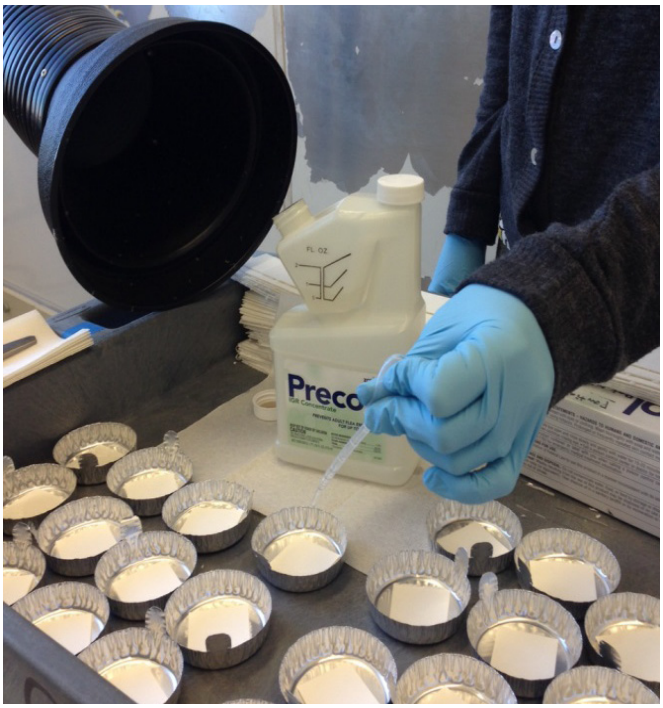
Gentrol concentrate and Precor concentrate were selected to test in two areas known to harbor heavy infestation, while continuing the program of Gentrol PointSource in all other areas.

One milliliter of the liquid concentrate was applied to each blotter square, which was then placed in each specimen drawer.[1] This quantity was chosen because it would more than match the exposure provided from on Gentrol PointSource, which was labelled for treating 75 sq. feet, assuming a ceiling height of an average domestic residence.[2]

Table 2 Comparison of alternative insect growth regulators

Brand name	Labelled for drugstore beetles?	IGR chemical name	Conc. in soln.	Vapor pressure
Gentrol® IGR concentrate	yes, as pantry pests, but primarily cockroaches; said to be less effective on cigarette beetles	s-hydroprene ethyl (E,E) – 3,7,11 – trimethyldodeca – 2,4 – dienoate ($C_{17}H_{30}O_2$)	9% in petroleum distillates	1.88×10^{-4} mm Hg (at 25° C)
Precor® IGR concentrate	not specifically, primarily fleas; said to work on cigarette beetles	s-methoprene isopropyl (E,E)-(RS)-11-methoxy-3,7,11-trimethyldodeca 2,4-dienoate ($C_{19}H_{34}O_3$)	1.2% in petroleum distillates	2.36×10^{-5} mm Hg (at 25° C)
Archer® IGR, NyGuard® IGR concentrate	not specifically, primarily fleas and cockroaches	pyriproxyfen 2-[1-methyl-2-(4-phen-oxyphenoxy)ethoxy] pyridine ($C_{20}H_{29}NO_3$)	1.3% in petroleum distillates	1.0 x 10-7 mm/Hg (at 20º C)
Gentrol® ` PointSource™	yes, as pantry pests, but primarily cockroaches	s-hydroprene	90.6% in petroleum distillates	1.88×10^{-4} mm Hg (at 25° C)
petroleum distillates	carrier for IGR products, listed for comparison purposes	molecular formula varies	100%	40 mm Hg (at 20º C)

(Health & Safety Executive, Biocides & Pesticides Assessment Unit 1996, Csondes 2004, Sullivan 2000, product label information, Professional Pest Control Products)



Consistency in spatial distribution was weighted over consistency in volume concentration, but many subjective decisions were made during the application because some cases are four times larger than the standard case size, some cases have very few drawers, and some cases have very many drawers. In general, we doubled the quantity for large cases and ensured that there were at least 10 blotters in every regular size case.

Starting at the most persistently infested end of the Mammals collection, one side of one aisle was treated with the Precor concentrate, the other side of the same aisle with the Gentrol concentrate. The remaining aisles in the range were treated with Gentrol PointSource following the original protocol.

Results

Already by what in some cases was the fifth round of Gentrol, we had noticed a reduction in the numbers of beetles in our windowsill traps within the collection range. We regarded this as a reliable indication of progress, since drugstore beetles are strongly attracted by light and inevitably ended up in this part of the room. It may also have been an indication that the adult beetles were not able to get past our Drione dust treatment of the case thresholds and spread further in the range. Eight weeks past the initial application of the test insect growth regulators, we inspected cases that had previously shown massive numbers of beetles. (Table 3)

While many cases showed some signs of continued infestation, such as a few beetle carcasses, the aisle which had been treated with Precor concentrate was the clear winner, with a total of 18 beetles compared with 111 in the row treated with Gentrol concentrate and 845 in the row treated with Gentrol PointSource. Thus encouraged, we proceeded to treat the rest of the collection range with the Precor concentrate.

To check the results of our Precor treatment, we returned to the persistently infested row in which Gentrol PointSource had been previously tested. Approximately 10 weeks after the cases in this row were thoroughly vacuumed and treated with Precor and Drione, some still showed the continued presence of the drugstore beetles, albeit in diminished numbers. Although we have not yet had a chance to evaluate the results for the entire collection range, the fact that our windowsill traps have remained empty indicates progress, if not necessarily victory.

Table 3 Results

Insect growth regulator product tested	Number of cases in sample[3]	Number of cases with no evidence of infestation	Number of cases with signs of continued infestation	Total numbers of beetles tallied
Precor® concentrate (s-methoprene)	28	12	16	18
Gentrol® concentrate (s-hydroprene)	30	9	21	111
Gentrol® PointSource™ (s-hydroprene)	30	2	28	845

Conclusions

Our work with insect growth regulators and, more specifically, our new approach using the insect growth regular s-methoprene has led to a reduction in the infestation, but is not a substitute for the fundamental freezing treatment. If anything, it has to be regarded as another tool in a comprehensive approach.

Insect growth regulators will continue to have a role in our management of the infestation, but may work best in preventing the reinfestation of specimens that are first treated by freezing. For example, if viable eggs remains in a case even after the specimens are frozen and the case vacuumed, the insect growth regulator may prevent the larvae from reestablishing the infestation by stopping them before they reach the reproductive adult stage. However, it would seem that many larvae that are already entrenched deep within a specimen are able to escape lethal exposure to the insect growth regulator applied to an infested case that has not yet undergone a freezing treatment.

While insect growth regulators have helped us gain the upper hand with a previously out-of-control infestation, we must continue to take a pest management approach to preventing further outbreaks and probably cannot ever regard the collection as "cured" of infestation.

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Parasitoid Wasps: an Unexpected Ally?

As you might imagine, when we started our use of insect growth regulator against the drugstore beetles in the Birds and Mammals collections, we were looking forward to seeing two things: either no bugs, or some other sign that the insect growth regulator had affected the life cycle of the beetles, such as incomplete metamorphosis. We were initially disappointed and perplexed to see more dead beetles, some live beetles, and some other unknown insects that we hadn't noticed before. Fortunately, we were able to take the unknown insects to our Entomology department for identification.

Imagine our surprise when we learned that the tiny insects were parasitoid wasps that had apparently been targeting the beetle larvae, laying their eggs in the larval bodies. Our Mammal Collection Manager's first reaction was, "Where can we get more of these wasps?"

As I soon learned, using parasitoid wasps as a pest control measure in museums is not that far-fetched. A study was conducted in five museums in Germany and Austria where parasitoid wasps were tested as a biological pest management strategy against drugstore beetles and webbing clothes moths. The wasps need to be released periodically within a confined area to effectively target the pest insect. The results of the study were very promising for drugstore beetles, although much less so for the webbing clothes moths. (Querner and Bieble 2011)

So why haven't we tried the parasitoid wasps – at least, why not on purpose? It turns out that they are easy to buy online from ecologically-minded pest control and garden supply companies. In fact, the use of beneficial insects to control pests is well established in agricultural and landscaping pest management. Frankly, I hesitated to introduce the parasitoid wasps partly because it sounded like the "There was an old woman who swallowed a fly"- approach to pest management. And the additional dead insect debris the wasps would leave behind might be attractive to other insect pests. But mainly, I was reluctant to consider introducing more wasps because we had already committed to our program of using the insect growth regulator and pesticide dust, both of which would interfere with the effectiveness of the wasps. So I filed parasitoid wasps away under "Plan B."

But you're probably still wondering how the wasps got into the collection in the first place! I asked the director of the museum's Nature Gardens whether they were using the wasps as biological control in the gardens overlooked by the collection range, but, while they were using some other interesting approaches, like a bacteria to target plant-eating moth larvae, the parasitoid wasps were not theirs. So I can only explain the occurrence of the wasps as one of the many wonders of nature, where there is always a creature waiting to exploit a new ecological niche. It also points out the porosity of our historic building, even with the collection room windows having been recently sealed.

Notes

1. Our method of delivering the concentrated insect growth regulator deviated from the product label instructions, which require that a measure of the concentrated liquid be diluted in water and applied as a spray. However, since we did not intend to apply the product directly to the specimens, a spray application would not have been appropriate for our needs. While "It is a violation of Federal Law to use this product in a manner inconsistent with its labeling," we embarked on our alternative application method using saturated blotters in aluminum dishes in the interests of testing its suitability for our situation. To ensure safety of staff, preparation of the product was done under fume extraction.

2. The amount of fluid in a Gentrol® PointSource™ unit is not indicated on any of the product labeling. We obtained an estimate of this amount by weighing a new unit and comparing its weight to an old, used unit. The difference in weight was .13 grams. Since petroleum distillates weigh around .8 g/mL (0.79g – 0.82 g / mL), we arrived at an estimate of 0.16 mL of fluid. At 90.6%, the s-hydroprene in the Gentrol® PointSource™ is about ten times more concentrated than in the Gentrol® concentrate.

3. In Table 3 Results, large cases were counted as their regular-size equivalent for purposes of comparison.

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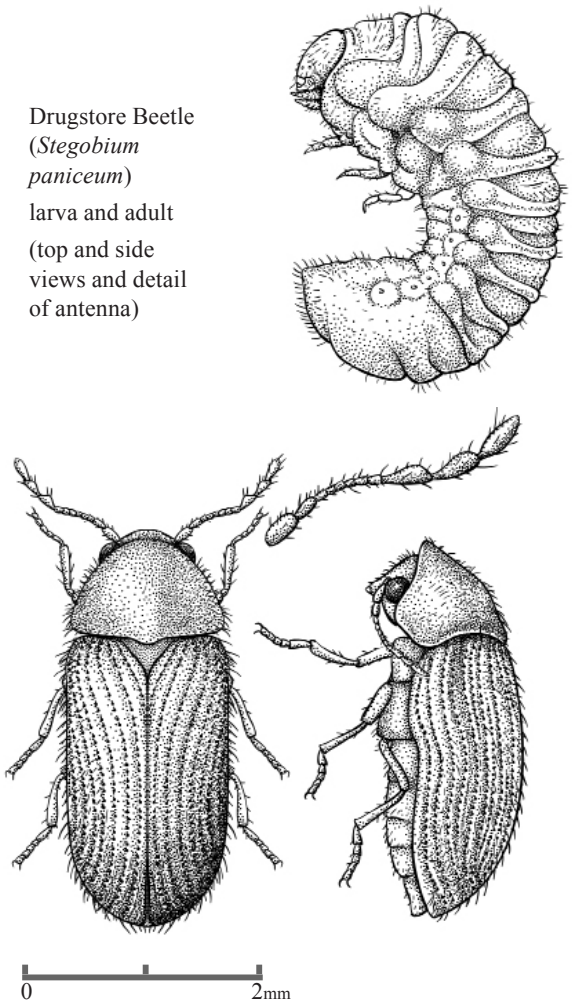

Illustration from *Insects of the Los Angeles Basin*, 2015, courtesy Natural History Museum of Los Angeles County