

Title: Evaluation of Exclusion to Prevent Indoor Infestations of the Brown Marmorated Stink Bug

Abstract: Brown Marmorated Stink Bugs (BMSB) are invasive insects considered an agricultural pest and a structural nuisance. Pest management professionals receive calls about this and other overwintering pests in the fall and spring when insects attempt to enter and exit structures, respectively. The goal of this research was to evaluate the effectiveness of physical exclusion in preventing indoor populations of BMSB. Twenty-three homeowners in a condominium complex in Hartsdale, NY agreed to participate, including 10 side-by-side units and one group of three. Gaps around windows and doors were eliminated in one unit per grouping with a standard, readily available sealant. Two light traps were installed in all homes to monitor stink bug populations, including SilenTraps in living spaces and GLOStiks in attics. Over a 15-month period that included three trapping sessions (fall 2015, spring 2016, fall 2016), a total of only eight overwintering pests were intercepted on SilenTraps. While two of the intercepted insects came from units that received exclusion, the remaining six came from control or untreated units. These findings are discussed in the context of pre- and post-survey results about the pest status of BMSB and regional trends in stink bug populations.

Introduction. The Brown Marmorated Stink Bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive insect from Asia that was accidentally introduced to the United States near Allentown, PA (Hoebeke and Carter 2003). Since its discovery in the 1990s, this pest has dramatically expanded its range and population size. In New Jersey alone, statewide trappings of stink bugs indicated a 75% annual population increase from 2004 to 2011 (Rice et al. 2014). Stink bugs can now be found in 42 US states and Canada, with new invasions occurring in the European countries of Switzerland, Liechtenstein, Germany, France and Italy (Rice et al. 2014).

Brown Marmorated Stink Bugs (BMSB) use piercing/sucking mouthparts to feed on over 100 different host plants (Bergmann et al. 2013), including ornamental and landscape plantings (Bergmann et al. 2016), agricultural crops (Cissel et al. 2015) and wild or woodland plants (Bakken et al. 2015). Feeding by BMSB can transfer plant pathogens or cause physical damage to crops, ultimately resulting in economic losses (Bergmann and Raupp 2014). In 2010, for example, the apple industry reported losses totaling \$37 million due to BMSB damage, while peaches, sweet corn, peppers, tomatoes, soybeans, and field corn were also severely damaged (Leskey et al. 2012a). Furthermore, vineyards, small fruit producers and ornamental growers are subject to damaging stink bug populations (Leskey et al. 2012b), while ecosystem impacts of this invasive pest remain unknown (Martinson et al. 2013).

For urban pest professionals, BMSB are a problem when they enter buildings as overwintering pests. Although the exact sequence of events has not been fully described, experience suggests that BMSB orient toward broad surfaces in the fall when temperatures, daylight or host plant quality decrease. Once on surfaces, BMSB seek dark cracks and crevices, and use their antennae to detect conspecific pheromones and locate other stink bugs (Toyama et al. 2006; 2011). Stink bugs remain hidden until warmer temperatures cause them to explore outside of their harborage. If on a warm winter afternoon, bugs inside homes may be attracted to the light of windows during the day, and artificial lights at night (Inkley 2012). As temperatures drop, BMSB retreat to hiding places, since diapause is not fully terminated until the photoperiod is between 14.8 and 15.5 hours and temperatures are sufficiently high (Rice et al. 2014). In the spring, overwintered BMSB leave homes and return outdoors to feed and reproduce.

Management of BMSB, both in agricultural and urban areas, has relied on insecticide applications to kill all life stages (Leskey et al. 2012b), and is particularly effective against nymphs and overwintered adults (Leskey et al. 2013). However, many products currently employed to control BMSB have reduced efficacy over time (Leskey et al. 2013), while label changes to pyrethroids limit how these products can be applied by urban pest management professionals. Furthermore, once pests are indoors, little can be done because the insects have no defined harborage. To provide alternatives, the use of essential oil

repellants (Zhang et al. 2014) and mass trapping with aggregation pheromones (Weber et al. 2014) have been investigated, but the practicality of these techniques for urban pest professionals is not yet known.

Physical exclusion is often promoted as a practice to reduce pest numbers indoors. Sealing cracks and crevices around doors, windows, utility access points, chimneys, siding and fascia have been promoted in extension bulletins and technical guides for BMSB (Day et al. 2011) and other overwintering pests. Despite its purported efficacy, to date there have been no scientific evaluations of pest exclusion, nor easy guidelines on how to implement this technique. Therefore, the goal of this research was to scientifically evaluate the use of physical exclusion to prevent invasion of BMSB and other overwintering pests.

Materials and Methods.

Location and Recruitment. This research took place at a condominium complex in Hartsdale, NY where residents identified BMSB populations as problematic for the last several years. The complex is approximately 30 years old and contains 145 units (Figure 1). Green spaces were set aside such that today there are mature trees both among the buildings and on the periphery of the property, which may serve as hosts to stink bugs. Buildings are uniformly designed, with T1-11 plywood siding painted stone grey. During the summer and fall of 2015, a large maintenance project saw the replacement of damaged siding, and all buildings were painted.

Within the complex, two to four individual units (condominiums) are joined to form a block (Figure 1). This design was ideal to test exclusion for a pair of units within a block, such that one unit underwent pest exclusion while the other did not. The intent was that end units could be compared, while interior or middle units could be compared, since these would have the same number of windows and access points.

Considering the role that vegetable, fruit and ornamental plants play in BMSB development, and that previous studies note stink bugs emigration from wooded areas into these production zones (Lee et al. 2014; Rice et al. 2016), it should be noted that a commercial nursery and small farm are located to the West of this complex (Figure 1). This could serve as a source population for stink bugs, explaining why the area is susceptible to invasion.

The 2100 square foot interior of condominiums consists of a finished basement, main level (kitchen, living and dining rooms) and second floor. Each home has an attached two-car garage, with an attic above. Attics can be accessed via a pull-down ladder in the garage, or through the second upstairs bedroom. A second attic space, rarely used by residents, is accessible above the second-floor bedrooms. In both attic spaces light is visible through slatted soffit vents (Figure 2).

Residents have the discretion to replace their windows, but nearly all units have the same double paned, sliding metal frame windows that were installed at construction (Figure 3). Based on their design, these windows have an outside flange that yields a gap between the window frame and the siding (Figure 4).

To recruit participants for the project, the management company sent an e-mail message to all residents in the community. The message specified that pairs of condominiums within a block were needed in order to participate. In total, 10 pairs and one triplet of condominiums enrolled in the project for a total of 23 units.

Exclusion Treatment. For each pair of units within a block, one was randomly selected (by coin toss) to receive the exclusion treatment, the other unit served as a control. In July 2015, all window and doorframes were inspected for gaps around flanges on treatment units. A readily available clear silicone-based sealant (DAP Dynaflex 230 ASTM C 920; DAP Products Inc., Baltimore, MD) was used to seal gaps around windows and doors where exclusion efforts had not been complete or the material failed. This did not include window weep holes, which allow water to drain from the structure (Figure 5). Sealant was applied only on sunny days to allow for complete curing of the product.

Sealant was examined in July 2016 (one year after application) to determine how the material held up after one full year. This examination included a representative sample of window and door frames from various portions of the complex, making special effort to inspect surfaces facing all cardinal directions, in full sun, full shade and variable sun/shade combinations.

Insect Monitoring. Two different insect light traps were utilized in each unit for this experiment, including the Catchmaster SilenTraps and the Catchmaster GLOStik Flying Insect Traps (AP&G Co., Inc., Brooklyn, NY). These devices were selected as products that can either be incorporated by pest management professionals in an overwintering pest elimination service, or sold to customers for the purpose of managing flying insects. SilenTraps require electricity, and were therefore used in living spaces (Figure 6), while GLOStiks are battery operated and could be placed in attics (Figure 2). Placement of devices was also based on personal safety, as glue boards in SilenTraps are protected, whereas the outer surface of GLOStiks could pose a risk to children and pets that touch the outer, sticky surface. Residents were asked to place SilenTraps where they had previously observed stink bugs and wanted to manage this pest.

Insect monitors (SilenTraps/GLOStiks) were operated from August-November 2015, March-May 2016 and September-November 2016. These periods correspond to the biology of BMSB and other overwintering pests that enter structures in the fall and attempt to exit in the spring. When devices were in operation, they were serviced once per month to replace batteries on GLOStiks and replace glue boards or GLOStik tubes as needed. Residents were also asked to keep track of the number of BMSB they observed during these times.

Resident Surveys. A preliminary survey was administered to residents in June 2015 for baseline information about BMSB activity within their unit (Appendix A), with a final survey was administered in November 2016 (Appendix B). Residents were asked to rate their experience with stink bugs, using the terms Minor, Moderate and Major Problem. These terms were qualified by arbitrary threshold numbers of insects based on action thresholds for crickets presented in Pinto and Craft (2000).

Results.

Location and Recruitment. Ten pairs of residents and one triplet (23 units) expressed interest in the experiment, corresponding to various parts of the complex (Figure 1). Most pairs included one end unit and one interior or middle unit. Despite initial interest in the project, several residents elected to drop out along the way. Reasons for not wanting to participate included irritation with light emitted by the SilenTrap in living spaces, the concern that the monitors would increase pest problems indoors, concerns about a lack of efficacy of traps, a perceived lack of a problem with BMSB (the individual enrolled because their neighbor requested their participation). Thus, only 13 of the original 23 units were involved until the end of the experiment.

Exclusion Treatment. Sealant was applied to windows and doorframes to prevent pest entry. Some gaps were larger than one inch, and therefore not amenable to being sealed with a silicone based sealant according to label instructions.

When inspected in July 2016, sealant in nearly all areas remained in good condition and provided effective exclusion to insect pests. An exception to this was where a large gap was present (approximately one inch) in an area that was constantly shaded and moist. In this location, the sealant had fallen out of the gap and had not cured correctly.

Insect Monitoring. A total of eight overwintering pests were collected during the study period (August 2015 to November 2016), exclusively on SilenTraps (Table 1). This included six BMSB, one Western conifer-seed bug (*Leptoglossus occidentalis* Heidemann) and one multicolored Asian lady beetle (*Harmonia axyridis* (Pallas)). Six of these overwintering insects were collected from control units, while

two were collected from treatment (exclusion) units. SilentTraps also harvested fungus gnats, large flies (*Calliphoridae* spp.), moths, beetles and other miscellaneous insects. No overwintering pests were collected on GLOSticks in attics. However, these traps captured several occasional invaders including underwing moths (Erebidae), click beetles, spiders and harvestmen (Opilines). The latter two were particularly abundant, and an interesting find for attics.

Residents reported observations of stink bugs in their homes. Of the seven homes that observed BMSB in the Fall 2015, five of them were control units that did not receive the exclusion treatment. Four of these residents reported seeing “many” BMSB. Residents in the two homes with exclusion indicated that they had observed one stink bug each. In Spring 2016, residents from ten units indicated that they had observed BMSB in their homes. Half (5) of these residents were from control units and reported seeing one to many (10+) BMSB in their home. The other half of residents that received the exclusion treatment reported one to two bugs in their homes, with the exception of one resident that reported seeing 12 BMSB. In the Fall 2016, five residents observed stink bugs: three of these were treatment units that observed one stink bug, while the two control units observed three and five stink bugs each.

Several residents observed BMSB in the same room as SilentTraps, but noted that the insects did not approach the device and were never found on the glue board.

Resident Surveys. Eighteen of the 23 residents responded to the preliminary survey, yielding a 78.3% response rate. Of those that responded, 66.7 % (n=18) indicated that BMSB were a problem in their homes for several years, and 71.4 % (n=18) regarded the pests as a moderate (4-7 bugs per year) to major problem (10+ bugs per year; Figure 7). A single resident indicated that they have never observed stink bugs in their home. Residents considered stink bugs to be a moderate to major pest problem, with half of the residents indicating that they observe ten or more bugs each year (Figure 8). Residents also identified a number of concerns that they have about stink bugs:

- bugs are found in areas where they sleep and sit, but not aware of why
- one resident did not want their neighbors infestation to affect their home
- one resident indicated that “typical sprays do not kill the stink bugs”
- residents feared that killing bugs would attract others to their home

Twenty-one of 23 residents responded to the post survey, a response rate of 91.3%. A similar percentage of residents indicated that BMSB were a problem prior to the study (Figures 9 & 10). During the study, residents indicated that stink bugs were not a problem (35%), a minor problem (45%) or a moderate problem (20%; n=21); no residents indicated that the pests were a major problem (Figure 11). There did not appear to be a difference in observed pest status based on treatment (Figure 12). When asked if problems with BMSB increased, decreased or remained the same, 68% of residents noted a decrease, while 32% (n=21) reported no change (Figure 13). This did not appear to differ based on treatment (Figure 14). For feedback on the SilentTrap, one resident indicated that it was “neat and uncomplicated,” three residents disliked the light from the trap, and another found the sound irritating.

Discussion: This experiment aimed to evaluate the use of exclusion as a technique to prevent indoor infestations of overwintering pests such as the brown marmorated stink bug, *Halyomorpha halys*. Unfortunately, low trap counts of intercepted insects precluded statistical analysis of results. Specifically, over a 15-month period that included three trapping sessions (fall 2015, spring 2016, fall 2016), a total of only eight overwintering pests were intercepted on traps that were placed inside the living space of homes. Two of these insects were from units that received exclusion, while six came from control or untreated units.

Given the lack of empirical data in this study, resident observations represent an alternative method of evaluating the project. In a preliminary survey, 66.7 % (n=18) of residents indicated that BMSB were a problem in their homes for several years, and 71.4 % (n=18) regarded the pests as a moderate (4-7 bugs per year) to major problem (10+ bugs per year). In a follow-up survey, residents

were consistent in stating that BMSB were previously an issue, with 66.7% considering them a moderate (4-7 bugs per year) to major problem (10+ bugs per year). However, during the study period, only 20% (n=21) of residents said that stinks bugs were a moderate problem (5-7 bugs per year), while none of the residents considered them to be a major problem. Furthermore, 32% of residents said that the pest status of stink bugs remained the same during the study, while the majority (68%) reported that stink bug problems decreased. No residents observed an increase in pest problems. This observed decrease in stink bug activity seemed to be independent of treatment, and suggests an overall decrease in stink bug problems. Several explanations may have contributed to both low catch and observation of overwintering pests.

Early anecdotes suggested that stink bugs and other overwintering pests prefer to enter buildings on the South and West side, where winter sunlight would buffer insects against cold temperatures. However, research by Funayama (2015) suggests that BMSB flight behavior is more complex such that the timing of air temperature changes could affect the cardinal direction of flight, while new evidence suggests that cool and dry locations are ideal for overwintering because they slow insect metabolism and enhance survival (Park and Goldner 2016). Based on this information, and the fact that units at the condominium complex are variably oriented, SilenTrap placement within a unit was not controlled. Instead, it was requested that residents place SilenTraps in rooms where stink bugs have been observed in the past. Once traps were plugged in, some residents elected to move devices to rooms they did not frequently occupy to avoid the low hum sound and light emitted by the devices. In other situations, residents requested to place devices behind furniture to reduce the amount of light. Given these circumstances, even if traps remained the only light source in the room at night, the opportunity for stink bugs to access the glueboard on traps may have been reduced, limiting trap catch.

GLOStiks, on the other hand, were always placed in attics, where previous observations indicate that BMSB overwinter utilizing cool, dry locations (Leskey et al. 2012a). Placing GLOStiks in attics was an attempt to determine if BMSB enter through attics, later gaining access to living spaces through light fixtures and gaps at wall-ceiling junctions. Large amounts of light were apparent via soffit vents, indicating that insects could enter through these open slats. Unfortunately, this question remains unanswered, as no overwintering pests were collected on GLOStiks despite capturing a variety of occasional invaders (harvestmen, spiders, underwing moths).

A related concern about trap placement is competition from other light sources. Two residents reported that stink bugs flew or crawled past light traps during the day. This behavior is not unexpected in the presence of natural light from windows or bright overhead lights. The expectation was that SilenTraps and GLOStiks would intercept these same insects at night when no other sources of light were available, especially since research has shown that BMSB are attracted to white, black and blue light (Leskey et al. 2015). In their evaluation of different light traps for intercepting BMSB, Aigner and Kuhar (2014) requested that study participants turn on experimental lights from 7pm to 7am, or they employed timers to automatically operate the traps at night. Even still, very few overwintering insects ended up on glue boards in the current study even though both SilenTraps and GLOStiks were effective at catching a number of occasional invaders and other pests in the homes. When considering observations and feedback from homeowners, it is suggested that SilenTraps are better suited for use in commercial settings that are constantly lit and noisy.

Recent reports suggest regional reductions in BMSB populations, which may provide the best explanation for low trap catches and decreased pest problems. Papers presented during the Medical and Urban Entomology session of the Eastern Branch of the Entomological Society of America meeting (1/4/2016, Philadelphia, PA) suggested that hot summers have desiccated stink bug egg-masses, and that native predators and parasitoids are beginning to recognize BMSB as a food source. Field studies in agroecosystems report egg loss percentages to parasitism and predation between 7.9 and 10.4%, with maximum levels of biological control estimated at 20% (Ogburn et al. 2016). Parasitism rates might continue to rise, especially considering the accidental introduction of a native egg-parasitoid natural

enemy of BMSB, *Trissolcus japonicus* (Ashmead) (Ogburn et al. 2016). For example, in the Hudson Valley, parasitism of sentinel egg masses was recorded at 70 to 90% (Jentsch 2016). Combined with predation and parasitism in natural areas, plus impacts to other life stages (nymphs and adults), natural control could be responsible for observed lower stink bug populations. Combined with other management techniques employed in agricultural areas such as pesticide applications (Rice et al. 2014), these factors may explain why residents in both treatment and control units reported a decrease in the pest status during the study.

The practice of exclusion is expanding in the pest management industry as a proactive, pest prevention method. Although this experiment was not able to measure an impact on pest exclusion of overwintering pests, it was valuable in providing lessons for pest professionals that choose to pursue this work, including material selection and safety.

The condominium complex where this study occurred was a simplified environment with little variation in the structure of windows and doors. Despite this consistency, the various openings encountered would require multiple materials for proper exclusion. Gaps less than one inch around windows and doors could be sealed with an exterior sealant, but window weeps and larger gaps require different materials that provide an exit for moisture to escape the frame and fill large voids, respectively. Although it has not yet been tested, the use of metal mesh fibers, such as Xcluder Strips (1" strips Xcluder material; Global Material Technologies, Inc., Buffalo Grove, IL) could be used in this setting to prevent overwintering pest entry while simultaneously allowing water to escape through the fibers. Where rodents and other wildlife are not a concern, expanding foam can be used to fill large gaps on the side of a window, with a sealant use to prevent moisture accumulation. For open soffit vents, screening would be needed to reduce the opening size and prevent pest entry. This could include the use of window screening or hardware cloth. A contractor may be needed to assess whether the selected material allows proper ventilation of the attic, while also excluding pests.

Exclusion for overwintering pests, occasional invaders and stinging insects, as well as wildlife, requires that technicians access all parts of the building, including the roofline. For this project, a 35-foot ladder was sufficient to reach all windows, but would not have reached soffits. Because of the potential hazards, individuals performing this work should undergo extensive ladder training, both as a ladder climber and spotter, to comply with regulations set forth by the United States Department of Labor Occupational Safety and Health Administration (OSHA: www.osha.gov/).

The brown marmorated stink bug has been extensively studied for its economic impact in agricultural systems, including efforts to understand food preferences (Acebes-Doria et al. 2016; Bergmann et al. 2016; Martinson et al. 2016), overwintering sites (Lee et al. 2014) and migration to production fields (Rice et al. 2016). However, limited research is available on the biology of this insect around structures (Park and Goldner 2016), likely because it is only considered a nuisance pest with no documented health impacts on people or physical damage to structures. But because BMSB and other overwintering pests cause distress for homeowners, the professional pest management industry needs effective methods to address these complaints. This may require researchers to take an observational approach and more completely characterize the overwintering biology of these insects.

For BMSB, references to overwintering biology are made in peer-reviewed literature, and it is thought that overwintering is triggered by decreasing photoperiod and temperatures (Hahn et al. 2016). Yet questions remain about BMSB movement on structures, how exactly they enter buildings, and where they overwinter once indoors. Basic observations can help to prioritize which zones on a home should be sealed to prevent pest entry. For example, it might be the case that stink bugs enter through soffit vents, or, it might be shown that the insects access homes through loose fitting windows or torn screens (Figure 15). While PMPs have access to materials that can prevent entry to soffits, window and screen replacement fall outside the realm of pest exclusion and require action on the part of the homeowner. Before entering in an agreement with a potential client, PMPs will want to know if pest elimination is possible to help set expectations for their customers.

This research was a first attempt at evaluating exclusion as a method to prevent indoor problems with overwintering pests. The results reported here should not be interpreted as negative results (i.e. that the treatment was ineffective), but rather a lack of results due to regional reductions in pest populations. Because trap catches were low the obtained data was not suitable for statistical analysis, precluding the ability to draw conclusions on the effectiveness of the treatment. Therefore, future efforts to explore exclusion of overwintering pests should begin with an evaluation of pest biology, followed by a validation of monitoring tool efficacy (light traps). If possible, trap placement within homes should be standardized, and residents should be asked to sign a memorandum of understanding about the research timeline and expectations for compliance. This might result in a higher completion rate.

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Appendix A – Preliminary Survey

Evaluation of Exclusion to Prevent Indoor Infestations of the Brown Marmorated Stink Bug
Preliminary Survey – June 2015

Thank you for your willingness to participate in this study! Our goal is to determine if sealing around windows, doors and other entry points can reduce the number of stink bugs that enter homes. The below survey is designed to obtain baseline information on the pest status of stink bugs in your home, and will be compared to a similar survey at the end of the study. No personal information will be utilized or published - unit numbers will be replaced by letters for anonymity. If you have any questions, please feel free to call or e-mail using the information above. Thank you!

1. What is the history of stink bugs in your unit?
 - a. I have never observed stink bugs in my home
 - b. 2014-5 was the first year I had stink bugs in my home
 - c. I have had stink bugs in my home for the last several years
 - d. I have had stink bugs in my home for the last several years, and every year I see more and more

2. How would you rate the overall pest status of stink bugs in your unit?
 - a. No problems to date
 - b. Minor problem (you see 1-3 stink bugs each year)
 - c. Moderate problem (you see 4-7 stink bugs each year)
 - d. Major problem (you see 10 or more stink bugs each year)

3. How would you rate the pest status of stink bugs in you unit **since August 2014**?
 - a. No problems to date
 - b. Minor problem (you saw 1-3 stink bugs in fall and spring)
 - c. Moderate problem (you saw 4-7 stink bugs in fall and spring)
 - d. Major problem (you saw 10 or more stink bugs in the fall in spring)

4. Which room(s) do you see the most stink bug activity? Are more stink bugs in the front (driveway side) or back?

5. Do you see any other pests in your home in the fall? If yes, please describe.

6. What are your biggest concerns about finding stink bugs in your home?

7. Your Unit Number: _____

Please return to guard station when completed. Address envelop "Attn: [REDACTED]"



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Appendix B – Post Survey

Stink Bug Program Evaluation – November 2016

Thank you for participating in the stink bug project! I am grateful for the opportunity to work with you in determining if exclusion can prevent stink bug problems indoors.

As part of the project evaluation, I would like your feedback on the project. ***Please fill out this survey even if you did not participate the entire time.*** Thank you!

8. Before the study (prior to June 2015), how would you rate the pest status of stink bugs in your home?
 - a. No problems
 - b. Minor problem (you saw 1-2 stink bugs each year)
 - c. Moderate problem (you saw 5-7 stink bugs each year)
 - d. Major problem (you saw 10 or more stink bugs each year)

9. During the study (June 2015 to November 2016), how would you rate the pest status of stink bugs in your home?
 - a. No problems
 - b. Minor problem (you saw 1-2 stink bugs in fall and spring)
 - c. Moderate problem (you saw 5-7 stink bugs in fall and spring)
 - d. Major problem (you saw 10 or more stink bugs in the fall in spring)

10. In your opinion, did stink bug problems increase, decrease or remain the same in your home during the study?
 - a. Increase
 - b. Decrease
 - c. Remain the same

11. What, if anything, did you **like** about the plug-in trap in your home?

12. What, if anything, did you **dislike** about the plug-in trap in your home?

13. Additional feedback:

14. Your Unit Number: _____

If you'd like to receive a copy of the final report, please provide your e-mail address or mailing address:

Please return to [redacted] at the guard station when completed. Thank you!!

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