Evaluation of pheromone traps and lures for trapping male *Agriotes sputator* (Coleoptera: Elateridae) beetles in eastern Canada

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Abstract

In North America, monitoring for *Agriotes* spp. click beetles typically has been done using Vernon beetle traps baited with bubble cap sex pheromone lures. This trap and lure are no longer produced commercially and a new trap, the Vernon pitfall trap, and lure design are used now for both invasive *Agriotes* and native pest species. Herein we compare the 2 trapping methods for *Agriotes sputator* (L.) (Coleoptera: Elateridae), and provide a calibration factor between them to allow comparison of survey results using the different methods. When deployed for the entire swarming season, Vernon pitfall traps fitted with the new capsule lures collect 0.7× as many *A. sputator* as Vernon beetle traps fitted with the bubble cap lures, and Vernon beetle traps fitted with capsule lures collect 0.5× as many beetles as Vernon beetle traps fitted with bubble cap lures. Unlike bubble cap lures, however, capsule-style lures need to be primed (maintained at room temperature for 3 wk) before deployment in the field, or else their initial attractiveness will be limited and trap catches will not be representative of populations present at the time. In addition, results from field studies indicate that these capsule lures deplete over the swarming season, and depending on the trapping objective (e.g., mass trapping) may need to be replaced after 5 to 6 wk of deployment. Increasing the lure load to 2× or 4× the regular 40 µL geranyl butanoate, or the capsule container size from 1.0 to 2.5 mL, did not significantly increase the number of *A. sputator* collected.

Key Words: wireworm; click beetle; mass trapping; monitoring

Resumen

En América del Norte, se han realizado el monitoreo de especies de *Agriotes* spp. (escarabajos saltapericos) generalmente utilizando trampas para escarabajos Vernon cebadas con señuelos de feromonas sexuales con tapa tipo burbuja. Esta trampa y señuelo ya no se producen comercialmente y una nueva trampa, la trampa de caída Vernon, y un diseño de señuelo se utilizan ahora tanto para las especies invasoras de *Agriotes* como para las plagas nativas. Aquí comparamos los 2 métodos de captura para *Agriotes sputator* (L.) (Coleoptera: Elateridae) y proporcionamos un factor de calibración entre ellos para permitir la comparación de los resultados de sondeo utilizando los diferentes métodos. Cuando se despliegan durante toda la temporada de enjambre, las trampas de caída Vernon equipadas con los nuevos señuelos de cápsula recolectan 0,7 veces más *A. sputator* que las trampas de escarabajos Vernon equipadas con los señuelos de tapa de burbuja, y las trampas de escarabajos Vernon equipadas con señuelos de cápsula capturaron 0,5 veces más escarabajos como trampas para escarabajos Vernon provistas de señuelos tipo burbuja. Sin embargo, a diferencia de los señuelos con tapa de burbuja, los señuelos tipo cápsula deben cebarse (mantenerse a temperatura ambiente durante 3 semanas) antes de su despliegue en el campo, o de lo contrario su atractivo inicial será limitado y las capturas con trampa no serán representativas de las poblaciones presentes en el campo a ese momento. Además, los resultados de los estudios de campo indican que estos señuelos de cápsula se agotan durante la temporada de enjambre y dependiendo del objetivo de captura (por ejemplo, captura masiva), es posible que sea necesario reemplazarlos después de 6 semanas de despliegue. El aumento de la carga de señuelos a 2 o 4 veces la cantidad del butanoato de geranilo normal de 40 µL, o el tamaño del recipiente de la cápsula de 1,0 a 2,5 mL, no aumentó significativamente el número de *A. sputator* recolectados.

Palabras Clave: gusano de alambre; escarabajos saltapericos; captura masiva; monitoreo

Larvae of 3 species of *Agriotes* click beetles have become serious pests of agriculture in Canada since their introduction from Europe in the 1800s (King et al. 1952; Eidt 1953; Vernon & van Herk 2013). Of these, *Agriotes sputator* (L.) (Coleoptera: Elateridae) is a particularly serious threat to potato and other vegetable production in eastern Canada (Noronha 2011), and *Agriotes obscurus* (L.) and *Agriotes lineatus* (L.) (both Coleoptera: Elateridae) are pests of vegetable, potato, and other field crops in both eastern and western Canada, and in the Pacific Northwest of the USA (Vernon & van Herk 2013, 2017). Researchers in Canada and Europe typically have relied on pheromone-baited traps for the adult beetles of these species to determine their distribution and spread (e.g., Furlan et

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al. 2001; Vernon et al. 2001; Blackshaw & Vernon 2006; Ivezic et al. 2007). Traps baited with these species-specific pheromones (*A. obscurus*: 1:1 geranyl hexanoate: geranyl octanoate; *A. lineatus*: 1:1 geranyl butanoate: geranyl octanoate; *A. sputator*: geranyl butanoate) also may be used to determine population change over time. For example, in Prince Edward Island in eastern Canada, large scale surveys were conducted in 2009, 2012, and 2016 by Agriculture and Agri-Food Canada and the Prince Edward Island Department of Agriculture and Forestry (Noronha 2017) to determine if populations of *A. sputator*, *A. obscurus*, and *A. lineatus* are increasing. Since 2000, the trap used for monitoring these species in Canada was the Vernon beetle trap (essentially a 15 × 15 × 5 cm high polyvinyl chloride box, dug slightly into the soil, with 2 ramps allowing beetles to walk, then fall into the interior holding area) (Fig. 1) (Vernon 2004), fitted with bubble cap pheromone lures produced by Contech Enterprises Inc. (Delta, British Columbia, Canada) (Vernon et al. 2001, 2014b; Blackshaw & Vernon 2006; LaGasa et al. 2006). After production of the Vernon beetle trap (Contech Enterprises Inc., Delta, British Columbia, Canada) was discontinued in 2014, the Vernon pitfall trap, a sturdy 10 cm deep × 9 cm diam circular polypropylene cup with a 3 cm wide collar along the rim, placed in soil up to the collar, and covered with a 16.5 cm diam lid that prevents entrance of insectivorous vertebrates (Fig. 1), was developed to fulfill the same purpose (van Herk et al. 2018). Since production of the bubble cap lure also was discontinued, the Vernon pitfall trap was designed to fit the plastic capsule-like lures that contained the same pheromone constituents as the above-mentioned bubble cap lures that was developed for *A. sputator*, *A. obscurus*, and *A. lineatus* monitoring in Europe (Yatlor funnel traps, developed by Furlan et al. [2001], and marketed by the Hungarian Plant Protection Institute MTA ATK, Budapest, Hungary). Early tests in Prince Edward Island indicated the Vernon pitfall trap was highly efficient for capturing *A. sputator* when baited with these lures, where traps in some areas collected up to 1,400 male *A. sputator* per trap per d (van Herk et al. 2018).

With the replacement of the bubble cap-baited Vernon beetle trap with the capsule lure-baited Vernon pitfall trap arose the need to compare the relative performance of these 2 approaches for collecting *A. sputator*, *A. obscurus*, and *A. lineatus*, particularly if the latter approach will be used in future to determine population increases relative to the earlier, Vernon beetle trap-based surveys. Comparison studies for *A. obscurus* and *A. lineatus* were conducted in British Columbia, Canada (Vernon & van Herk, unpublished data), and here we report on 4 field studies conducted in Prince Edward Island to compare the Vernon pitfall trap fitted with various capsule lures with the Vernon beetle trap fitted with either bubble cap or capsule lures for capturing *A. sputator*. These data will facilitate the selection and comparison of new Vernon pitfall traps and lures with results from earlier surveys in Prince Edward Island for *A. sputator*, such that future survey data can be calibrated to determine changes in *A. sputator* populations. We also compared the relative longevity of the bubble cap and capsule lures to determine if lure replacement mid-season is necessary with the new trapping approach.

Materials and Methods

Field studies were conducted at 3 locations in southeastern Prince Edward Island: 1 each in 2016 and 2019, and 2 in 2017. Trap types evaluated were the Vernon beetle trap (Vernon 2004) and the recently developed Vernon pitfall trap (Fig. 1) (van Herk et al. 2018). Pheromone lures evaluated included the bubble cap lure, containing 175 µL geranyl butaonate (Contech Enterprises Inc., Delta, BC, Canada) designed to fit into 1 of the ramps of the Vernon beetle trap (Vernon & Toth 2007; Vernon et al. 2014a), and capsule lures, containing 40 µL of geranyl butanoate, designed to fit in the bottom center of the Vernon pitfall trap lid (van Herk et al. 2018). Capsule lures were purchased from either the Hungarian Plant Protection Institute MTA ATK (CSALOMON®, Budapest, Hungary) (hereafter "commercial" lure) or made by the authors (hereafter "experimental" lure). Standard experimental lures were made using 1 mL LDPE sample vials (8 mm diam, 0.98 mm wall thickness; Kartell Labware, Noviglio, Italy) filled with a single 100% cotton pellet (Richmond Dental #0, Charlotte, North Carolina, USA), onto which 40 µL of geranyl butanoate (Penta Manufacturing, Fairfield, New Jersey, USA) was pipetted. Additional 1 mL experimental lures were made with 160 µL of geranyl butanoate pipetted onto 1 or 4 cotton pellets. Larger-diam experimental lures were made using 2.5 mL LDPE sample vials (14 mm diam, 0.83 mm wall thickness; Kartell Labware, Noviglio, Italy) filled with a single cotton pellet, onto which 40, 80, or 160 µL of geranyl butanoate was pipetted. Lures were stored at −20 °C immediately after production. To determine if there is a delay in the time required for the pheromone to permeate the capsule wall and become detectable, standard experimental lures were deployed in traps directly upon removal from the freezer (hereafter "non-primed lures"), or removed from the freezer and held for 21 d at room temperature (about 20 °C) (hereafter "primed lures"). The bubble cap lures used in these studies always were deployed in traps directly upon removal from the freezer (i.e., were non-primed). Commercial lures were kept in a freezer by the supplier until shipment, during which they were at ambient, early spring temperatures for 2 to 3 wk. Hence the exact length of time the commercial lures were outside of freezing conditions is unknown (i.e., prior to, during, or after the shipment period), and they were considered non-primed. The experimental lures used in 2017 studies were primed.

Although lure release rates were not obtained during these studies, prior testing conducted by Contech Enterprises Inc. (J. P. Lafontaine, personal communication) suggests that under laboratory conditions (about 20 °C and no air movement), the release rate of standard capsule lures for *A. sputator* is approx. 0.35 mg per d after 10 d, declining linearly to about 0.15 mg per d after 80 d, and for *A. lineatus* and *A. obscurus* is 0.2 mg per d and 0.1 mg per d after 10 and 80 d, respectively. Release rates for bubble caps for *A. sputator* could not be obtained, but rates for *A. lineatus* and *A. obscurus* bubble cap lures at 20 °C are much higher (about 0.5, 0.7 mg per d at 10 d, respectively; and 0.3, 0.5 mg per d at 80 d, respectively). These release rates will differ under field conditions.

2016, OCEANVIEW FIELD

The 2016 study was conducted within a 1.6 ha field at Oceanview, Prince Edward Island, Canada (46.068120°N, 62.819844°W) (hereafter "Oceanview field") and compared the Vernon beetle trap with bubble cap lure, Vernon pitfall trap with commercial lure, Vernon pitfall trap with commercial and primed experimental lures, and Vernon pitfall trap with primed and unprimed experimental lures to determine which method collected most *A. sputator* beetles over a season. Traps were placed in 2 straight, parallel transects, each containing 3 replicates of the study. The study followed complete randomized block design, with replicates within each row separated by a minimum of 20 m, and traps within a replicate likewise placed 20 m apart. Traps were placed on 1 Jun 2016 in cultivated, vegetation-free soil, and checked once or twice per wk until 3 Aug (collection dates listed in Table 1). Due to Vernon beetle trap traps being removed on 17 Jun to allow for field planting (to brown mustard, *Brassica juncea* [L.] Czern.; Brassicaceae) and not replaced until 21 Jun, direct per-date comparisons between this trap and treatments involving Vernon pitfall trap were not done after this date. Comparisons of the Vernon pitfall

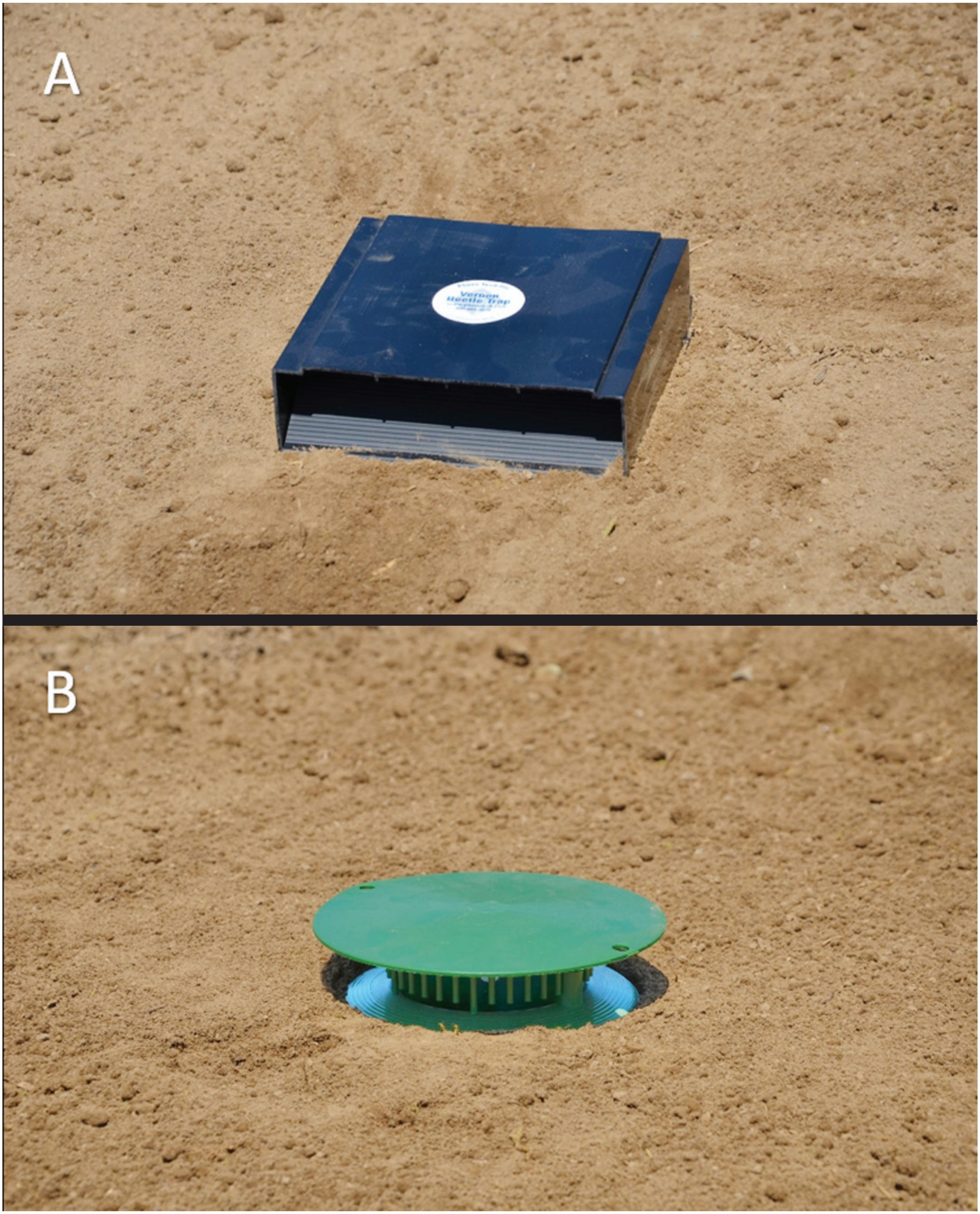

Fig. 1. Vernon beetle trap (A) and Vernon pitfall trap (B) designed for collecting *Agriotes obscurus*, *Agriotes lineatus*, and *Agriotes sputator* click beetles, shown installed for optimum capture in the field.

Table 1. Mean (SD) number of *Agriotes sputator* beetles collected in Vernon pitfall traps and Vernon beetle traps in Oceanview field in Prince Edward Island, Canada, in 2016 (n = 6 replicates). Traps were placed 1 Jun 2016. Except for the 21 Jun collection, data for the entire replicate was removed from mean and ratio calculations if 1 or more traps in the replicate were compromised.

Collection date	A: Vernon pitfall trap with commercial lure (non-primed)	B: Vernon pitfall trap with experimental lure (non-primed)	C: Vernon pitfall trap with experimental lure (primed)	D: Vernon beetle trap with bubble cap lure (non-primed)	Ratio: A:C (similar lure, different priming)	Ratio: B:C (same lure, different priming)	Ratio: A:D (different lure and trap)	Ratio: C:D (different lure and trap)
2 Jun	77.2 (17.5) C	9.0 (2.5) D	180.7 (23.8) B	267.3 (89.9) A	0.43	0.05	0.29	0.68
4 Jun	95.2 (26.0) C	45.5 (20.7) C	163.0 (63.4) B	221.7 (97.8) A	0.58	0.28	0.43	0.74
7 Jun	110.2 (88.8) BC	81.7 (27.0) C	160.5 (72.3) B	281.8 (121.0) A	0.69	0.51	0.39	0.57
10 Jun*	149.3 (93.5) C	122.5 (53.4) C	255.6 (143.2) B	360.5 (357.4) A	0.65	0.52	0.45	0.69
17 Jun	208.3 (104.1) B	167.7 (84.5) B	289.3 (191.9) A	322.7 (133.0) A	0.72	0.58	0.65	0.90
21 Jun	200.0 (146.0) A	209.2 (80.2) A	240.0 (101.9) A	No data	1.00	1.05	–	–
28 Jun	22.7 (23.2) A	20.8 (14.9) A	19.2 (12.2) A	66.7 (43.9) A	1.18	1.09	–	–
4 Jul	11.2 (4.1) A	11.5 (6.1) A	9.0 (4.9) A	19.8 (10.6) A	1.24	1.28	–	–
12 Jul	11.0 (4.8) A	12.3 (7.4) A	11.0 (5.1) A	38.5 (31.9) A	1.00	1.12	–	–
19 Jul	5.3 (3.4) A	2.0 (1.7) A	2.5 (2.8) A	6.8 (5.6) A	–	–	–	–
25 Jul	4.2 (3.1) A	1.8 (1.5) A	2.5 (2.1) A	0.8 (1.3) A	–	–	–	–
3 Aug	0.7 (1.6) A	0.5 (0.8) A	0.2 (0.4) A	0 (0) A	–	–	–	–
Mean (SD): 1 Jun to 3 Aug	885.3 (430.9) BC	672.8 (194.1) C	1,250.8 (426.9) AB	1,537.0 (651.4) A	0.71	0.54	0.58	0.81
Mean (SD): 1 to 17 Jun	630.3 (310.7) BC	414.7 (149.8) C	1,006.5 (478.5) AB	1,404 (698.1) A	0.63	0.41	0.45	0.72
Proportion of total collected 1 to 17 June	3,782 of 5,312 = 0.71	2,488 of 4,037 = 0.62	6,039 of 7,505 = 0.80	8,426 of 9,222 = 0.91				

*For the 10 Jun collection, n = 5; numbers within a row followed by the same letter are not statistically different from each other; primed lures were retrieved from the freezer 11 May 2016.

trap fitted with primed versus unprimed experimental lures, and of experimental versus commercial lures were possible for all dates, however, and the 3 Vernon pitfall trap treatments were reinstalled in the field immediately after planting on 17 Jun (i.e., same day as removal).

2017, HOYTZ AND DELIGHTS FIELDS

The 2017 and 2019 studies were conducted along field edges, with replicates placed in continuous, straight lines along the field perimeters ("headlands") where they are commonly placed for monitoring (van Herk & Vernon 2020). Care was taken to ensure all traps within a replicate were surrounded by similar vegetation, and that the immediate headland sections surrounding them were similar in width and elevation relative to the inside of the field. Headland vegetation in these studies was characterized by a mixture of grasses, goldenrod (*Solidago canadensis* L.; Asteraceae), and vetches (*Vicia* spp. L.; Fabaceae). All studies had a complete randomized block design.

Both 2017 studies were conducted near Orwell Cove, Prince Edward Island, Canada. Study 1 was conducted in the headlands of the "Hoytz field" (46.149051°N, 62.840841°W; field area 3 ha) and compared Vernon pitfall traps fitted with blank (no pheromone), commercial, and standard (primed) experimental lures to determine the relative efficacy of the latter 2 lures. Replicates (8) were separated by a minimum of 40 m. Traps were placed 20 m apart down the center of the headlands (about 4 m wide) on 1 May 2017 (immediately before the start of the swarming season in 2017), and checked weekly until 1 Aug (Table 2). Study 2 was conducted in the headlands of the "Delights field" (46.147096°N, 62.857501°W; field area 6 ha) and compared Vernon pitfall traps fitted with commercial lures, regular (primed) experimental lures, experimental lures with 4× pheromone load on 1 or 4 cotton pellets, and larger 2.5 mL lures with 1, 2, or 4× pheromone load on 1 cotton pellet (Table 3). Replicates (6) were separated by at least 20 m. Traps were placed 15 m apart down the center of the headlands (about 4 m wide) on 4 May 2017, and checked weekly until 1 Aug (Table 3). One of the replicates was eliminated from the study due to disturbance from field equipment. This study allowed for comparisons between the commercial and standard experimental lure, and determined the effect of increasing lure load and lure surface area on *A. sputator* captures.

2019, DELIGHTS FIELD

The 2019 study also was conducted in the "Delights field" headlands, with Vernon beetle traps fitted with either bubble cap or commercial lures, and Vernon pitfall trap with commercial lures which were replaced either halfway through the swarming period or retained for the duration of the study. Replicates (10) were separated by at least 20 m, and traps were spaced 10 m apart. Traps were placed on 22 May 2019 and checked each wk until 22 Jul and once again on 13 Aug (Table 4). The purpose of this study was to determine the relative efficacy of (1) Vernon beetle traps and Vernon pitfall trap fitted with the same lure type, (2) Vernon beetle traps fitted with 2 different lure types, (3) Vernon beetle traps with bubble cap lures (previous monitoring method) and Vernon pitfall trap fitted with commercial lures (new monitoring method), and (4) Vernon pitfall traps that had either 1 continuous or 2 consecutive commercial lures in terms of total *A. sputator* captures over a season.

No preservatives or killing agents were used in these studies, and all captured insects were collected at each trap check. Captured insects were placed in ethanol after capture until they could be processed. Trap count data were normalized when necessary, then analyzed with both ANOVA (PROC GLM, SAS 9.2) for total counts over the season, and repeated measures analysis to compare trap captures on individual dates (PROC MIXED, SAS 9.2).

Table 2. Mean (SD) number of *Agriotes sputator* beetles collected in Vernon pitfall traps baited with different pheromone lures in Hoytz field in Prince Edward Island, Canada, in 2017.

Collection date	A: Non-baited Vernon pitfall traps	B: Vernon pitfall traps baited with commercial lure (non-primed)	C: Vernon pitfall traps baited with experimental lure (primed)	Ratio: B:C
8 May	0.3 (0.5) A	10.3 (13.2) A	10.4 (10.6) A	0.99
18 May	0.4 (0.7) A	88.4 (56.4) A	116.6 (71.1) A	0.76
25 May	0.3 (0.7) A	668.9 (661.6) B	552.3 (604.9) B	1.21
31 May	0.4 (0.7) A	213.6 (215.8) AB	228.5 (213.1) B	0.93
8 Jun	0.3 (0.5) A	195.0 (160.0) B	177.8 (135.2) B	1.10
14 Jun	0.1 (0.4) A	331.5 (487.1) B	306.8 (233.2) B	1.08
21 Jun	0 (0) A	333.3 (532.3) B	362.0 (416.0) B	0.92
27 Jun	0 (0) A	273.4 (264.1) B	316.1 (314.6) B	0.86
4 Jul	0 (0) A	128.3 (205.3) A	135.0 (126.3) A	0.95
11 Jul	0 (0) A	173.4 (206.3) B	189.3 (146.2) B	0.92
19 Jul	0 (0) A	158.0 (111.4) B	109.3 (92.3) AB	1.45
25 Jul	0 (0) A	91.5 (106.7) A	60.6 (69.1) A	1.51
1 Aug	0 (0) A	107.1 (85.1) A	65.5 (50.3) A	1.64
Mean (SD): 1 May to 1 Aug	1.63 (1.41) A	2,772.5 (2,354.4) B	2,630.0 (1,103.4) B	1.05

Numbers within a row followed by the same letter are not statistically different from each other; *n* = 8 replicates.

Results

2016, OCEANVIEW FIELD

Significant differences were observed between treatments (F = 10.70; df = 3,15; P = 0.0005) and between replicates (F = 7.05; df = 5,15; P = 0.0014) in the total number of *A. sputator* beetles collected in 2016, and in the numbers collected 1 to 17 Jun (F = 13.49; df = 3,15; P = 0.0002; F = 6.91; df = 5,15; P = 0.0016, respectively), with the highest numbers occurring in the Vernon beetle trap with bubble cap lures despite these traps being removed from the field for 4 d (Table 1). Repeated measures analysis of individual collection dates similarly indicated significant differences between treatments (F = 59.52; df = 3,173; P < 0.0001), replicates (F = 22.83; df = 5,173; P < 0.0001), and collection dates (F = 99.97; df = 11,173; P < 0.0001), but also in the relative performance of treatments over time (treatment × collection date: F = 5.86; df = 32,173; P < 0.0001). Of note is that virtually no other click beetles were collected in traps baited with *A. sputator* pheromone in this or any of the studies reported herein.

Vernon pitfall traps baited with primed experimental lures collected significantly more (46%) *A. sputator* beetles than non-primed lures (Table 1, column C versus B: t = 3.48; P = 0.016), and this was most evident from 2 to 17 Jun (Fig. 2A), where weekly collections were always significantly higher with primed lures. After 17 Jun, traps with primed and non-primed lures collected approximately equal numbers (Table 1). Vernon pitfall traps baited with primed experimental lures also collected numerically more (29%) *A. sputator* than traps baited with commercial lures (Table 1, column C versus A: t = 2.20; P = 0.17). The lower numbers collected with the commercial lures (significant at P < 0.05 for 2, 4, 10, and 17 Jun; Table 1) also may be due to these not being sufficiently primed prior to deployment (Fig. 2A). Despite the missing collection date, more beetles were collected overall in Vernon beetle traps with bubble cap lures than Vernon pitfall traps with primed experimental lures (19% lower catch) or non-primed commercial lures (42% lower catch), but only the latter treatment was statistically significant (Table 1, column C versus D: t = 1.73; P = 0.35; column A versus D: t = 3.93; P = 0.0066, respectively).

2017, HOYTZ FIELD

Significant differences were observed between treatments (F = 11.04; df = 2, 14; P = 0.0013) but not replicates (F = 1.83; df = 7, 14; P = 0.16) in the total number of beetles collected (Table 2). Numbers collected overall in Vernon pitfall traps baited with non-primed commercial and primed experimental lures were similar (Table 2, columns B and C: t = 0.21; P = 0.98) (Fig. 2B). Repeated measures analysis of individual collection dates also indicated significant differences between treatments (F = 70.90; df = 2, 182; P < 0.0001), as well as between replicates (F = 11.77; df = 7, 182; P < 0.0001) and collection dates (F = 12.48; df = 12, 182; P < 0.0001), and in the relative performance of treatments over time (treatment × collection date: F = 3.29; df = 24, 182; P < 0.0001). The latter was due to differences in the ratio of captures with commercial and experimental lures from 8 May to 11 Jul (range 0.76–1.21) and 19 Jul to 1 Aug (range 1.45–1.64; Table 2). This may have been due to experimental lures depleting slightly earlier, or to the relatively low numbers collected at the end of the season which then skewed ratios.

2017, DELIGHTS FIELD

Similar numbers were collected in all 7 treatments (24,086–28,826; Table 3), and differences between them were not statistically significant (F = 0.27; df = 6, 24; P = 0.94). However, significant differences were observed between replicates (F = 4.95; df = 4, 24; P = 0.0047). As in the other 2017 study (Hoytz field), numbers collected overall in the Delights field in Vernon pitfall traps baited with non-primed commercial and primed experimental lures were nearly identical (Table 3, columns A and B: t = 0.26; P = 1.00) (Fig. 2C). Repeated measures analysis of individual collection dates also indicated significant differences between replicates (F = 21.36; df = 4, 312; P < 0.0001) and collection dates (F = 169.25; df = 12, 312; P < 0.0001), but not between lure types (F = 1.19; df = 6, 312; P = 0.31) or in the relative performance of treatments over time (treatment × collection date: F = 1.02; df = 72, 312; P = 0.45).

2019, DELIGHTS FIELD

Significant differences were observed between treatments (F = 5.66; df = 3, 27; P = 0.0039) and replicates (F = 5.73; df = 9, 27; P = 0.0002) in the total number of beetles collected (Table 4). Repeated measures analysis of individual collection dates also indicated significant differences between treatments (F = 30.08; df = 3, 265; P < 0.0001), replicates (F = 25.06; df = 9, 265; P < 0.0001), and collection dates (F = 125.29; df = 9, 265; P < 0.0001), and in the relative performance of treatments over time (treatment × collection date: F = 2.54; df = 27, 265; P < 0.0001).

Table 3. Mean (SD) number of *Agriotes sputator* beetles collected in Vernon pitfall traps baited with different pheromone lures in Delights field in Prince Edward Island, Canada, in 2017.

Collection date	A: commercial lure (non-primed)	B: experimental lure (primed)	Experimental lure with 4× pheromone and 1× cotton (primed)	Experimental lure with 4× pheromone and 4× cotton (primed)	2.5 mL experimental lure with 1× pheromone (primed)	2.5 mL experimental lure with 2× pheromone (primed)	2.5 mL experimental lure with 4× pheromone (primed)	Ratio: B:A
8 May	11.8 (9.9)	6.8 (5.9)	17.0 (20.6)	14.4 (25.0)	7.8 (8.9)	17.4 (20.1)	9.6 (12.4)	0.58
18 May	57.2 (30.6)	61.8 (13.8)	57.6 (42.4)	61.6 (33.9)	61.4 (40.6)	69.6 (26.3)	76.4 (54.4)	1.08
25 May	827.6 (414.3) A	983.2 (807.5) AB	955.8 (691.4) AB	805.8 (602.1) A	1,238.8 (733.7) C	1,055.8 (678.9) BC	1,127.6 (729.3) BC	1.19
30 May	438.8 (231.7)	472.0 (326.7)	561.0 (370.4)	466.4 (351.2)	577.8 (419.2)	511.2 (278.0)	461.2 (240.8)	1.08
8 Jun	1,138.6 (681.9) AB	1,322.0 (916.5) B	1,205.4 (441.7) AB	1,372.2 (994.5) B	1,177.6 (672.4) AB	1,144.4 (769.4) AB	994.2 (703.0) A	1.16
14 Jun	1,072.6 (310.8) ABC	886.0 (641.1) A	1,144.4 (244.0) BC	1,266.8 (643.1) C	1,178.2 (581.0) BC	839.0 (389.9) A	1,005.4 (336.3) AB	0.83
21 Jun	583.4 (333.8) AB	557.8 (473.2) AB	400.6 (400.9) A	617.8 (678.6) AB	644.8 (399.8) B	474.0 (425.4) AB	672.4 (527.0) B	0.96
27 Jun	321.0 (310.3)	307.4 (288.2)	147.2 (189.7)	329.2 (430.3)	247.6 (238.1)	122.6 (182.0)	269.6 (217.2)	0.96
5 Jul	74.0 (76.3)	142.2 (120.7)	157.2 (215.7)	166.2 (341.5)	184.4 (199.3)	71.4 (146.9)	124.6 (162.0)	1.92
11 Jul	212.2 (120.0)	107.8 (122.2)	260.0 (129.5)	194.8 (100.1)	171.6 (195.1)	229.0 (133.9)	316.4 (392.9)	0.51
19 Jul	115.4 (51.1)	138.4 (99.4)	166.8 (121.0)	60.6 (41.1)	64.0 (58.3)	108.8 (55.1)	137.8 (135.2)	1.20
25 Jul	111.0 (73.2)	147.6 (87.0)	140.2 (91.6)	186.0 (149.4)	72.4 (46.2)	98.6 (58.6)	112.4 (90.7)	1.33
1 Aug	94.6 (63.7)	160.0 (71.1)	157.0 (84.3)	223.4 (241.8)	62.2 (70.2)	75.4 (33.9)	111.0 (34.3)	1.69
Mean (SD): 4 May to 1 Aug	5,058.2 (1,130.4)	5,293.0 (2,293.6)	5,370.2 (1,125.3)	5,765.2 (2,655)	5,688.6 (1,449.4)	4,817.2 (1,921.7)	5,418.6 (1,180.7)	1.05

Numbers within a row followed by the same letter are not statistically different from each other; $n = 5$ replicates.

Table 4. Mean (SD) number of *Agriotes sputator* beetles collected in Vernon pitfall trap and Vernon beetle pheromone traps in Delights field in Prince Edward Island, Canada, in 2019. Traps were placed 22 May 2019. $N = 10$ replicates, unless otherwise indicated. Lures in column A were replaced on 2 Jul.

Collection date	A: Vernon pitfall trap with commercial lure (non-primed) replaced after 2 Jul (41 d after start of study)	B: Vernon pitfall trap with commercial lure (non-primed) not replaced	C: Vernon beetle trap with commercial lure (non-primed)	D: Vernon beetle trap with bubble cap lure (non-primed)	Ratio: A:B (same lure, same trap)	Ratio: B:C (same lure, different trap)	Ratio: B:D (different lure and trap)	Ratio: C:D (same trap, different lure)
31 May	155.1 (87.3) A	121.8 (77) A	96.3 (34.9) A	220.0 (173.3) B	1.27	1.26	0.55	0.44
4 Jun*	41.3 (45.7) A	45.1 (60.8) A	35.1 (30.0) A	98.2 (71.8) A	0.92	1.28	0.46	0.36
11 Jun**	395.3 (381.8) B	437.0 (469.3) B	299.6 (329.3) A	663.0 (584.3) C	0.90	1.46	0.66	0.45
17 Jun	641.6 (427) B	702.1 (403.8) B	401.4 (248.9) A	700.9 (375.1) B	0.91	1.75	1.00	0.57
25 Jun*	540.0 (227.9) B	629.6 (357.3) BC	390.0 (255.5) A	722.0 (483.2) C	0.86	1.61	0.87	0.54
2 Jul	73.6 (69.2) A	80.2 (102.8) A	69.2 (92.8) A	147.0 (235.2) A	0.92	1.16	0.55	0.47
8 Jul	85.4 (154.1) AB ***	32.7 (60.5) A	51.1 (67.8) AB	157.5 (240.9) B	2.61	0.64	0.21	0.32
16 Jul	104.5 (184.6) AB ***	37.3 (65.0) A	27.4 (28.6) A	156.0 (243.3) B	2.80	1.36	0.24	0.18
22 Jul	41.9 (95.7) A ***	6.7 (13.4) A	1.6 (4.4) A	59.2 (113.4) A	6.25	4.19	0.11	0.03
13 Aug	56.6 (107.7) AB ***	26.3 (33.0) AB	8.1 (12.3) A	130.7 (227.6) B	2.15	3.25	0.20	0.06
Mean (SD): 22 May to 13 Aug	1,998.1 (1,144.6) AB	1,963.9 (1,020.8) AB	1,277.4 (798.0) B	2,839.9 (1,822.6) A	1.02	1.54	0.69	0.45
Mean (SD): 22 May to 2 Jul	1,709.7 (852.7) AB	1,860.9 (968.9) AB	1,189.2 (731.7) B	2,336.5 (1,182.3) A	0.92	1.56	0.80	0.51
Mean (SD): 8 Jul to 13 Aug (% of total)	288.4 (536.0) A (12.6%)	103.0 (120.3) A (5.0%)	88.2 (98.8) A (6.5%)	503.4 (790.5) A (15.1%)	2.80	1.17	0.20	0.18

*Mean and ratio calculations in rows based on 9 replicates; **Mean and ratio calculations in row based on 8 replicates; ***Indicates lures in traps were replaced on 2 Jul. Numbers within a row followed by the same letter are not statistically different from each other.

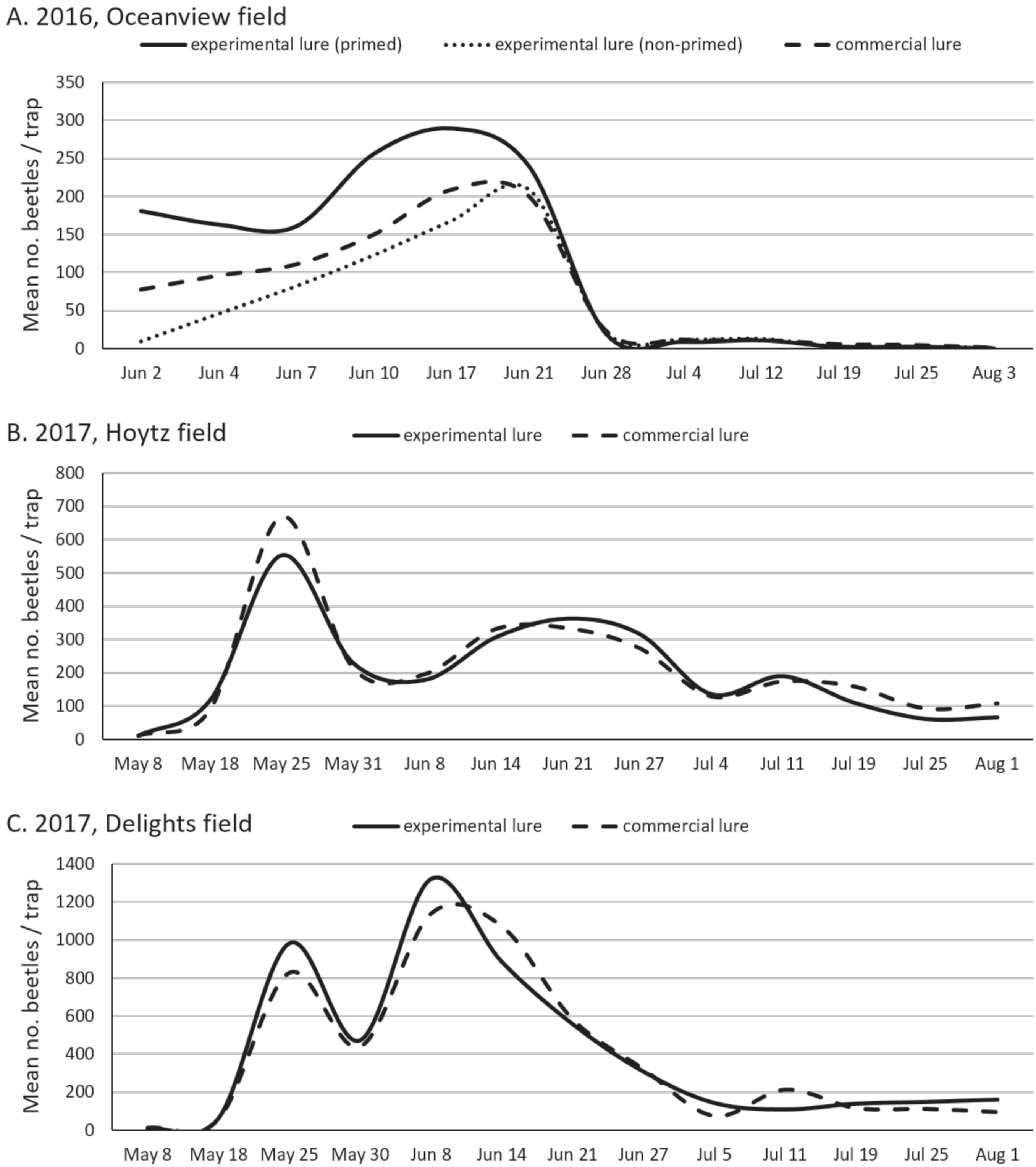

Fig. 2. Capture of *Agriotes sputator* using Vernon pitfall traps baited with commercial and experimental lures throughout the swarming season in 3 fields in Prince Edward Island, Canada. Note the close correspondence between the 2 lure types in 2017, but not in 2016. Primed lures were placed at room temperature 3 wk before deployment, whereas non-primed lures were kept at −20 °C until deployment

More beetles (54%) were collected in Vernon pitfall traps than Vernon beetle traps, both baited with partially primed commercial lures, but this difference was not statistically significant (Table 4, column B versus C: t = 1.80; P = 0.29), and was more pronounced before 2 Jul (56%) than thereafter (17%; Table 4). Vernon beetle traps baited with non-primed commercial lures collected significantly fewer beetles overall than the same trap baited with bubble cap lures (55% less; Table 4, column C versus D: t = 4.11; P = 0.0018). This was most notable after the 2 Jul trap check, when captures were 82% less (Table 4). The decline in performance of Vernon beetle traps with commercial lures relative to Vernon beetle traps with the bubble cap lures suggests the former were losing effectiveness more quickly. Evidence of this was provided by comparing Vernon pitfall traps in which commercial lures were replaced with fresh (non-primed) lures after the 2 Jul check with Vernon pitfall traps that retained the original lure until the end of the study. Whereas the total capture in these 2 treatments was similar (Table 4, column A versus B: $t = 0.09$; $P = 1.00$), this was due to the lure replacement occurring after the main swarming period was over (i.e., > 80% of beetles had been collected by 2 Jul, Table 4). Comparison of the numbers collected by these treatments indicates the treatment which had 2 consecutive lures typically collected fewer than the other prior to 2 Jul (likely due to spatial variability in trap catch, because these treatments were identical in all respects prior to 2 Jul) (Table 4, column A:B: mean ratio 22 May–2 Jul: 0.92), but that this trend reversed thereafter (mean ratio 2 Jul–13 Aug: 2.80). As a result, the proportion of the total collected after 2 Jul in Vernon pitfall traps with lures replaced was significantly higher than in those with non-replaced lures (Chi = 941; df = 1; $P < 0.0001$), confirming that capsule lures lose efficacy over time.

Comparison of the proportion (of total) beetles collected after 2 Jul in Vernon pitfall traps and Vernon beetle traps with a single, non-replaced commercial lure over the season (5.0, 6.5%; Table 4) with the proportion collected during this period by Vernon beetle traps with bubble caps (15.1%) or Vernon pitfall traps with replaced lures (12.6%), suggests the latter 2 methods are similar in terms of the duration of beetle capture. According to this study, Vernon pitfall traps with either 1 continuous, or 2 consecutive capsule lures will collect 0.69 to 0.70× the number of beetles collected by Vernon beetle traps with bubble caps over the entire swarming season (Table 4, column B versus D: $t = 2.30$; $P = 0.12$; A versus D; $t = 2.21$; $P = 0.15$, respectively).

Discussion

PRIMING, CAPSULE LURE TYPE, AND DEPLETION

Data from the 2016 study indicates lures should be primed (i.e., kept at room temperature for 2–3 wk) before being deployed in the field (Fig. 2A). During the peak collection period (2–17 Jun), non-primed experimental lures collected about half as many *A. sputator* beetles as primed experimental lures. This is attributed to the duration primed experimental lures were placed at room temperature before deployment, because both lure types were identical in all other respects (they were randomly chosen from a single batch of standard experimental lures manufactured the same d). Therefore, use of improperly primed lures may lead to considerable population underestimations early in the beetle swarming season when collections typically are highest. This in turn may have adverse consequences for crop protection, particularly if click beetle numbers are used to determine if and when insecticides need to be applied for managing the beetle stage. Equally important, deployment of improperly primed lures may lead to the underperformance of pheromone baited traps used in male *A. sputator* mass trapping programs, resulting in a lower proportion of females remaining unmated.

Whereas the 2016 data indicated the commercial lure performed less well than the primed experimental lure, collecting 29% less beetles overall (Table 1, column A versus C), this mostly was due to their underperformance immediately after deployment, coinciding with the peak season (2–17 Jun), and may have been due to the commercial lures not being sufficiently primed (Fig. 2A). The latter is plausible because the commercial lures were exposed only to ambient temperatures (likely considerably lower than room temperature) during the approximately 2 wk of transit after their purchase. Data from the two 2017 studies indicate a close correspondence in captures with the 1 mL commercial capsule lures and the 1 mL primed experimental lures throughout the season (Fig. 2B, C), suggesting the experimental lures (with sufficient priming) can be used alongside or in place of the commercial lures.

Data from 2019 show that the non-primed commercial capsule lures are depleted more quickly than bubble cap lures, both in Vernon pitfall and Vernon beetle traps. Based on ratios of captures in Vernon pitfall traps with replaced and non-replaced commercial capsule lures (Table 4: ratio column A: column B), Vernon pitfall traps with capsule and Vernon beetle traps with bubble cap lures (ratio B:D), and Vernon beetle traps with capsule and bubble cap lures (ratio C:D), the depletion observed would have occurred after the 2 Jul trap check, at which point most of the swarming period was over. This suggests that if Vernon pitfall traps with capsule lures are deployed for monitoring the presence or absence, or relative size of beetle populations, lure replacement mid-season may not be necessary, because the lures performed well during the early swarming period when the majority of beetles are typically captured, and when various adult control strategies would have already been initiated (i.e., mass trapping or population spraying). This would eliminate the extra labor and costs involved for lure replacement. However, if the traps are deployed specifically to mass trap males and prevent mating, it may be better to replace lures after 4 or 5 wk instead of 6 (as done in 2019) to reduce the likelihood lure attractiveness is reduced during the main swarming period. Replacement lures would need to have been properly primed before deployment. It is notable, however, that whereas lure depletion was evident, the total numbers collected in Vernon pitfall traps using 1 continuous versus 2 consecutive lures was virtually identical. Had the main swarming period extended into Jul, differences between these treatments would have been more pronounced.

CAPSULE SIZE AND VOLUME OF PHEROMONE

The similar, large numbers of beetles collected in all 7 treatments regardless of capsule size, number of cotton pellets, or pheromone load in 2017, suggest that these modifications to the standard experimental lure will not enhance the capture of *A. sputator* in Vernon pitfall traps. Whereas mean comparisons indicated significant differences in capture for some dates (e.g., more in large [2.5 mL] than standard [1 mL] lures with 1× pheromone load on 25 May; in standard 1 mL lures with 4× (1 or 4 cotton pellets) than 1× pheromone load on 14 Jun; in large rather than standard lures with 4× pheromone load on 21 Jun) (Table 3), there was no apparent or consistent pattern between increases in lure load and capture (e.g., compared with captures with large lures on 14, 21, and 27 Jun). Interestingly, there was a weak trend in captures with the large lures on 11 Jul to 1 Aug that suggested large lures with 2× and 4× were collecting more than those with 1× pheromone load (Table 3), but this may indicate slower rates of depletion in the former due to increased amount of pheromone. The same trend was not apparent with the standard 1 mL lures. Similar captures in capsule lures with 1× to 4× pheromone loads may suggest the rate of diffusion of the pheromone through the capsule wall is the limiting step in the attractiveness of the capsule. As shown, bubble cap lures, which have a similar (175 µL) load as the 4× capsules (160 µL), are more attractive than capsule lures, but diffusion occurs through a thin membrane in bubble cap lures rather than the relatively thick LDPE wall of the latter, and hence is much more rapid (as noted above).

OVERALL PERFORMANCE OF VERNON PITFALL TRAP RELATIVE TO VERNON BEETLE TRAP

The ratio of male *A. sputator* beetles collected in Vernon pitfall traps with standard commercial capsule lures versus Vernon beetle traps with bubble cap lures was relatively similar in 2016 (Table 1, ratio C:D = 0.81 for 1 Jun–3 Aug; 0.72 for 1–17 Jun) and 2019 (Table 4, ratio B:D = 0.69 for 22 May–13 Aug; 0.80 for 22 May–2 Jul). Trap comparisons for 2019 likely were more accurate, because catches were based on a longer trapping period (the collection period started later and ended earlier in 2016), the 2019 study was more robust (more replicates), and data sets were more complete (i.e., there was no missing Vernon beetle trap data as had occurred in 2016), so we can estimate the relative capture in Vernon pitfall traps with standard commercial capsule lures to be about 0.7× that collected in Vernon beetle traps with bubble cap lures. Because Vernon pitfall traps with capsule lures replaced halfway through the swarming season continue to attract beetles as long as Vernon beetle traps with bubble caps, we recommend this method to be an acceptable replacement of the previous monitoring approach.

Vernon beetle traps typically are used for several seasons, and some of them are still available and can be deployed with standard commercial capsule lures. This approach was used for the large scale surveys for *A. sputator* conducted by Agriculture and Agri-Food Canada and the Prince Edward Island Department of Agriculture and Forestry in Prince Edward Island in 2019 (S. Ibarra, personal communication). Based on the numbers collected in 2019 (Table 4, ratio columns C:D), Vernon beetle traps baited with standard commercial lures likely will collect approximately 0.5×, or slightly less, than would be collected by Vernon beetle traps with bubble cap lures, in part due to earlier depletion of the capsule lures. We suggest, therefore, that to compare the results of the 2019 Agriculture and Agri-Food Canada survey with those of earlier Agriculture and Agri-Food Canada surveys conducted in 2009, 2012, and 2016 (Vernon beetle traps baited with bubble cap lures), the 2019 trap catches should be multiplied by 2× to approximate the numbers that would have been collected had the 2019 Vernon beetle traps been baited with bubble cap lures rather than commercial lures.

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