Use of Japanese-beetle traps to monitor flight of the Pacific coast wireworm, *Limonius canus* (Coleoptera: Elateridae), and effects of trap height and color

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ABSTRACT

Japanese-beetle traps were used to monitor flight of the Pacific coast wireworm, *Limonius canus* LeConte, in an agricultural field in northern Oregon. Overwintered beetles first appeared in traps in mid-March 2000 and 2001, and were collected until mid- to late-May both years. Most (93%) of the females collected at the beginning of the flight period had been inseminated, which may indicate that mating takes place very soon after beetles emerge from the soil. Sex ratios favored males at the beginning of the flight period and favored females at the end of the flight period. Lower temperatures in April 2001 compared to those in 2000 may have caused a delay in timing of the peak catch (relative to timing in 2000) by almost 3 weeks. A count of over eight beetles per trap per 7-day sampling interval was obtained during the week of peak catch in April 2000. Traps were hung at three heights:1.5, 0.9, and 0.3 m above ground. Catch decreased with increasing trap height. Traps that had been painted yellow collected more beetles than traps painted white, which in turn collected more beetles than traps painted red, green, dark blue, or black. Two other elaterids, *Ctenicera pruinina* (Horn) and *Cardiophorus montanus* Bland, were also trapped during the study.

Key words: *Limonius canus*, click beetles, monitoring, flight, trap

INTRODUCTION

The Pacific coast wireworm, *Limonius canus* LeConte (Coleoptera: Elateridae), inhabits irrigated soils of western North America, where it is a pest of grain and vegetable crops (Gibson 1939; Lane and Stone 1960). Like other wireworm species (Stone 1941; Lane and Stone 1960), *L. canus* requires several years to complete its life cycle (Landis and Onsager 1966). The insect overwinters in the soil primarily in the larval stage as a mix of ages. Final-instar larvae pupate in summer, and the pupae eclose into the adult stage in fall and winter. Adults remain in the soil during the winter, emerging the following spring apparently in response to increasing soil temperatures. Life span of the overwintered (post-emergence) adult appears to be no longer than 2 months (Toba 1986).

There is a critical need for research on this and other wireworm pests that could lead to advances in managing these insects (Jansson and Seal 1994). Research into new ways of sampling populations is needed, to allow studies of population biology and to assist growers in making management decisions (Jansson and Seal 1994). Much of the previous research done on sampling these insects has concentrated on the larval stage (e.g., Onsager 1975; Toba and Turner 1983; Williams *et al.* 1992). Considerably less study has focused on the adult click beetle, despite the fact that the adult stage is responsible for spreading wireworm infestations (Boiteau *et al.* 2000).

This study tests whether traps that were developed to monitor Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), might be used to sample adult *L. canus*.

Japanese-beetle traps have several advantages over other traps used to sample click beetles (including sticky traps, window interception traps, and water pan traps), in that they are simple to set out in the field, are easily monitored, and require no adhesive materials such as tanglefoot to trap the insect. We used these traps to document the flight period of male and female *L. canus* in an agricultural field located in north-central Oregon, and determined if seasonal trends in trap catch were associated with air temperature. Second, traps were placed at different heights to learn if catch depended upon height of the traps above ground, as shown for other Elateridae (Boiteau *et al.* 2000). Third, we compared traps of different colors to monitor their effectiveness. Finally, we dissected female beetles trapped on one date at the beginning of the female flight period to determine if they were mated. Other wireworm species mate very soon after emergence from the soil in spring (Stone 1941; Zacharuk 1962), but it is not known whether *L. canus* exhibits similar behavior.

MATERIALS AND METHODS

All studies were conducted between March and May, 2000 and 2001 at the Agricultural Research and Extension Center, Oregon State University, Hermiston, Oregon. Yellow, four-vaned Japanese-beetle traps (Trécé, Salinas, CA) were hung on metal poles in a fallow field adjacent to a circle of irrigated wheat. The same location was used both years of the study. Ten poles were set out in a line at spacings of approximately 20 m. Three traps at different heights were hung on each pole: 1.5 m, 0.9 m, and 0.3 m above ground. Vegetation in the surrounding field and immediately beneath the traps was cut by a mower or by hand to prevent plants from obscuring the lowest traps. Clear glass jars were used as the collecting reservoirs beneath the traps. Jars were emptied every 7 d between March and May. Click beetles were counted, identified, and categorized to sex. Air temperature data were obtained from a weather station located at the study site and maintained by Experiment Station personnel.

Trap catch data were compared among trap heights using analysis of variance, with each pole being considered a block. To determine if trap catch increased or decreased as a linear or curvilinear function of height, linear and quadratic contrasts were extracted in each analysis.

A second study was done to determine the effects of trap color on catch. The visible surfaces of yellow Japanese-beetle traps were painted with one of six colors (Krylon High Gloss paints, Sherwin-Williams, Cleveland, OH): Sun Yellow Gloss, Glossy White, Emerald Green, Banner Red, Gloss Black, and True Blue Gloss. Traps were hung at 0.3 m above ground on fence lines at the Hermiston Experiment Station during the same time interval as the height tests. In 2000, traps were placed at the northern edge of the station adjacent to plots of wheat and potatoes. Catch of *L. canus* was small here, so in 2001 the traps were moved 200-500 m to the south, where they were hung 0.3 m above ground on fence lines adjacent to an irrigated circle of wheat. Six traps of each color were set out in a randomized complete-block design with six replicates. Adjacent traps within a block were approximately 5 m apart. Adjacent blocks were separated by at least 20 m. Traps were emptied weekly, and click beetles were counted, identified, and sexed. Data were analyzed using analysis of variance followed by an LSD-test to separate treatments (trap colors).

To determine whether the first female *L. canus* collected in traps in 2001 had been inseminated, we dissected beetles that had been collected on 1 May during the height test. On 24 April, 2001, water was added to each collecting jar on each trap to prevent beetles from mating while in the jar. Water was used rather than a preservative to avoid the possibility that odors from the preservative might affect trap catch. The collecting jars received water from rainfall at irregular intervals over the course of the studies, so the presence of water in the jars was not something unusual. Jars were collected 1 week later and samples were taken to the laboratory. Female *L. canus* were dissected in alcohol to remove the internal reproductive organs, using the drawings of Becker (1958) and Zacharuk (1958) as visual reference. The spermatophoral receptacle (Zacharuk 1958) was then examined under a dissecting microscope to determine whether a spermatophore was present. If no spermatophore was found, the internal organs were teased apart with dissecting needles, crushed on the microscope slide, and examined for sperm using a compound microscope at 100-400x (in other Elateridae absence of a spermatophore does not indicate lack of mating, as the spermatophore is slowly broken down in the female; Zacharuk 1958). Decomposed beetles were not dissected.

Voucher specimens have been deposited with the M.T. James Entomology Museum, Washington State University, Pullman.

RESULTS

The largest weekly catch of *L. canus* in the height test was about three-fold higher in 2000 than 2001 (Fig. 1). Beetles began showing up in traps in mid- to late-March apparently in response to warming temperatures (Fig. 1). We captured beetles well into May both years. The peak in captures occurred almost 3 weeks later in 2001 (1 May sample) than in 2000 (12 April sample). Moreover, the peak catch contained a much larger percentage of females in 2001 than 2000 (see below). Lower temperatures in late March and early April 2001 relative to conditions in 2000 may have caused reduced levels of flight activity in 2001 compared to levels over the same time interval in 2000 (Fig. 1).

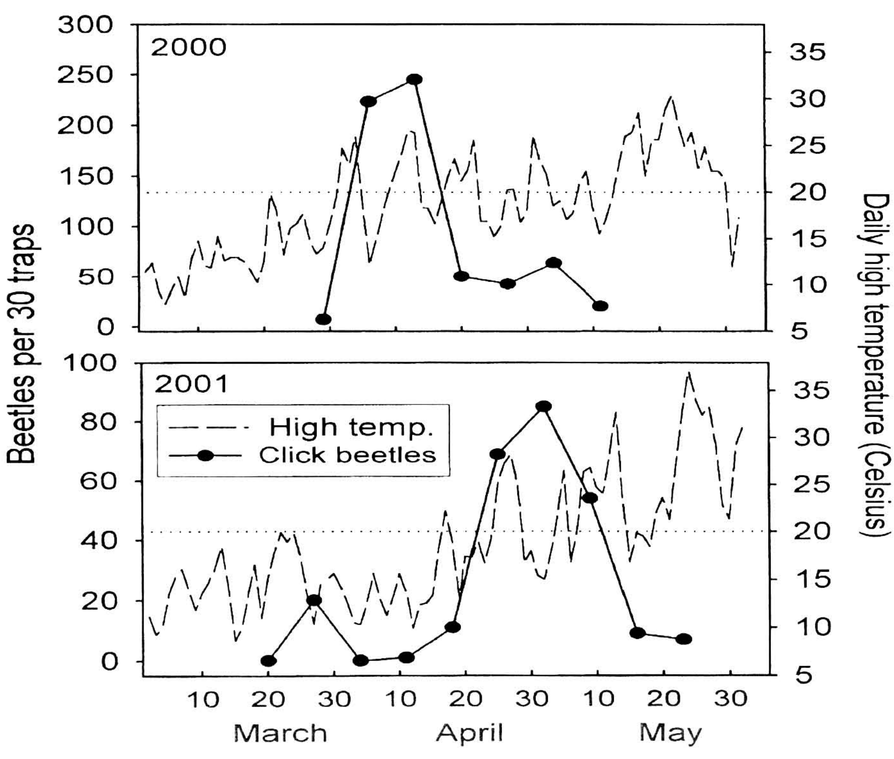

Figure 1. Numbers of *L. canus* collected in 30 traps (10 poles x 3 traps per pole) per week (solid lines) and daily high air temperatures (dashed lines); Hermiston Agricultural Research and Extension Center, Hermiston, Oregon. Horizontal dotted line at 20° C included in each panel to provide perspective.

Males predominated in the March and April samples, whereas females were more abundant than males in samples obtained in May (Figs. 2-3). Samples obtained during peak flight had a much higher proportion of males in 2000 (88.6% male [217/245 beetles]; 12 April sample) than in 2001 (50.6% male [43/85 beetles]; 1 May sample). Total numbers of male beetles collected over the sampling period was larger in 2000 than in 2001 ($\bar{x}$ = 50.4 beetles per three traps in 2000 vs 15.6 beetles per three traps in 2001; F = 131.5, df = 1,18, P < 0.001; numbers pooled for the three traps on the same pole and summed across dates). Totals for females were similar between years ($\bar{x}$ = 14.7 beetles per three traps in 2000 vs 10.1 beetles per three traps in 2001; F = 3.2, df = 1,18, P = 0.09). In both years, numbers decreased with increasing height of the trap (Figs. 2-3).

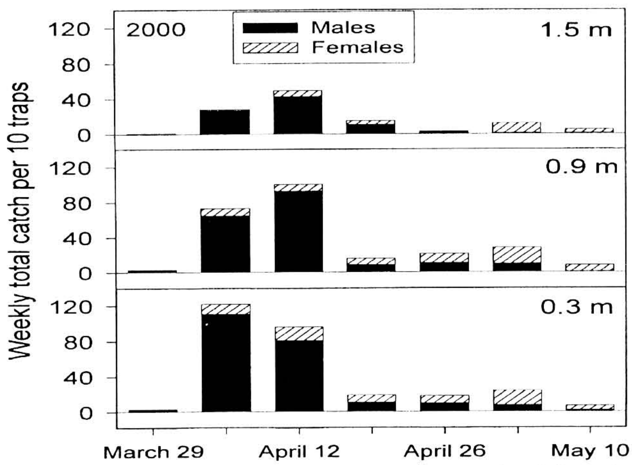

Figure 2. Weekly total catch of *L. canus* per 10 traps at each of three heights; 2000 data. Mean number of beetles per trap (sexes combined; summed over 7-week sampling period): 28.9 (0.3 meters), 24.9 (0.9 meters), and 11.3 (1.5 meters); F = 29.2; df = 2,18; P < 0.001 (contrasts: linear effects of height, P < 0.001; quadratic effects of height, P = 0.03).

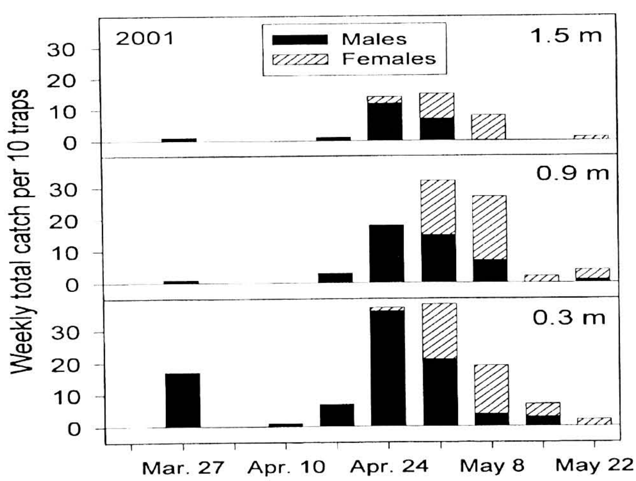

Figure 3. Weekly total catch of *L. canus* per 10 traps at each of three heights; 2001 data. Mean number of beetles per trap (sexes combined; summed over 10-week sampling period): 13.0 (0.3 meters), 8.7 (0.9 meters), and 4.0 (1.5 meters); F = 16.6; df = 2,18; P < 0.001 (contrasts: linear effects of height, P < 0.001; quadratic effects of height, P = 0.88).

Click beetles other than *L. canus* collected in the traps included *Ctenicera pruinina* (Horn), *Cardiophorus montanus* Bland, and unidentified *Dalopius* and *Melanotus* (Table 1). Of these, *C. pruinina* (Great Basin Wireworm) is a known pest of vegetable and grain crops in the Pacific northwest. Most of the beetles were collected in the lower and middle traps, as with *L. canus*. Sex ratios were male-biased (Table 1).

Few *L. canus* were collected in the 7-week test of trap color done in 2000 (Table 2). The traps were moved to a different area of the station in 2001 with better results. In 2001 (10 weeks), traps that had been painted yellow caught significantly more *L. canus* than white traps (Table 2), and either color caught more beetles than the blue, green, red, or black traps. Samples had male-biased sex ratios in all trap colors (Table 2). Other species collected included *C. pruinina* and *C. montanus*.

Thirty-nine female *L. canus* were dissected from the 1 May, 2001 samples in the height test. Of these females, 14 contained a spermatophore, 22 contained sperm but no spermatophore, and in 3 females we failed to find either a spermatophore or sperm.

Table 1

Click beetles other than *L. canus* collected in Japanese-beetle traps during height test (summed over sampling dates); M - males, F - females.

	1.5 meters		0.9 meters		0.3 meters	
	M	F	M	F	M	F
29 March - 10 May 2000						
Ctenicera pruinina (Horn)	1	0	1	0	5	0
Cardiophorus montanus Bland	0	1	7	2	7	3
Dalopius sp.	1	0	1	0	3	1
27 March - 22 May 2001						
Ctenicera pruinina	1	0	6	0	2	0
Cardiophorus montanus	1	0	5	0	10	4
Melanotus sp.	0	0	0	1	0	0

Table 2

Click beetles collected in Japanese-beetle traps of different colors. Numbers are totals for the 7-week (2000) or 10-week (2001) sampling periods. M - males, F - females. Six traps per color. Analysis of variance for the 2001 *L. canus* data (summing data for sexes) showed significant differences among colors ($F = 13.9$; df = 5,25; $P < 0.001$). An LSD-test showed significantly ($P < 0.05$) higher catches in yellow traps than in white traps, which in turn had significantly more beetles than green, black, blue, or red traps.

	Yellow		White		Green		Black		Blue		Red	
	M	F	M	F	M	F	M	F	M	F	M	F
29 March - 10 May 2000												
Limonius canus	5	1	4	0	3	0	2	0	1	0	1	0
Ctenicera pruinina	0	0	0	0	1	0	0	0	3	0	0	0
Cardiophorus montanus	5	1	2	1	2	1	4	1	5	1	0	0
27 March - 22 May 2001												
Limonius canus	43	12	24	11	14	3	13	4	11	5	9	5
Ctenicera pruinina	0	0	0	0	4	0	1	0	0	0	1	0
Cardiophorus montanus	1	0	0	0	1	0	0	1	0	1	0	0

DISCUSSION

There is a need for both basic and applied research on the Elateridae to improve our understanding of these insects but also to provide the knowledge necessary to develop more effective management programs for the pest species (Jansson and Seal 1994). In many pest Elateridae, the larval stage has received considerably more study than the adult stage (Boiteau *et al.* 2000). This bias may reflect the difference in longevity between larvae and adults, and also the fact that adult click beetles do little damage. Thus, for many pest Elateridae, we still lack basic information about the biology of adults, including details about phenology, mating behavior and sex pheromones, fecundity, egglaying, feeding habits, and dispersal.

Several of these research topics, particularly phenology and dispersal, require having tools that can be used in the field to monitor movements by the adult beetle. A variety of techniques have been used to monitor flying click beetles, such as sweep nets (Shirck 1942), water pan traps (Iwanaga and Kawamura 2000), window interception traps (Boiteau *et al.* 2000), sticky traps (Furlan 1996), and funnel-vane traps (Iwanaga and Kawamura 2000). For species that spend most or all of their adult lives on or near the ground, adult beetles have been trapped using mats of cut vegetation (Gough and Evans 1942; Roebuck *et al.* 1947) and pitfall traps (Doane 1963). These different sampling methods have been used to determine direction of flight (Lafrance 1963), dispersal distances (Doane 1963), phenology (Lafrance 1963), reproductive status of females (Shirck 1939), and response to chemical attractants (Iwanaga and Kawamura 2000).

We tested whether traps that were designed to monitor Japanese beetles could be used to monitor flight of *L. canus* and other Elateridae. Japanese-beetle traps are commonly used to monitor flight activity of Coleoptera other than the Japanese beetle, particularly other Scarabaeidae (Crocker *et al.* 1999). Metzger and Sim (1933) listed species and numbers of Elateridae that were caught in Japanese-beetle traps placed in an area of New Jersey, and showed that large numbers of a species of *Melanotus* were collected in the traps. The Elateridae that we collected were composed mostly of *L. canus*, but we also collected small numbers of other species. The low numbers of these other species were probably due to low densities in the study area rather than to trap inefficiency. That is, larval collections made at the station over the last several years have been mostly *L. canus* (unpubl.).

Limonius canus adults were active between mid-March and mid- to late-May (Fig. 1). Emergence of the adults in March was probably in response to warming soil temperatures, as suggested for other Elateridae (Lafrance 1963). Flight appears also to have been affected by temperature, because trap catch dropped substantially in late March and early April 2001 coinciding with 2 weeks of maximum air temperatures below 20^{o} C (Fig. 1). Shirck (1939) stated that cool conditions prevented flight by a closely related species, the sugarbeet wireworm (*Limonius californicus* (Mannerheim)), and Doane (1961) showed that numbers of *Ctenicera destructor* (Brown) captured in funnel traps dropped in cool weather. Because of the cooler temperatures in 2001, the peak catch of *L. canus* occurred almost 3 weeks later in 2001 than 2000 (Fig. 1). Also, total trap catch over the duration of the study was lower in 2001 than 2000, largely because of the reduced flight activity of male *L. canus* during April 2001. The sex ratios (Figs. 2-3) show either that males emerged earlier in spring than females, or that males were more likely than females to engage in flight during March and early April. Others have shown that male Elateridae emerge in spring before females (Stone 1941; Shirck 1942; Zacharuk 1962). Male *Limonius agonus* (Say) emerge 1 to 3 days earlier than females (Begg 1962). Seasonal totals of beetles in the height test were composed of relatively more males in 2000 (77.4% of beetles) than in 2001 (60.8%), probably due to the reduced catch of males in April 2001 associated with cooler temperatures.

Efficient use of Japanese beetle traps to monitor *L. canus* requires information about the roles of trap color and placement in affecting catch. Although based upon relatively small numbers of beetles, traps that had been painted yellow collected significantly more *L. canus* than traps painted white, which in turn collected significantly more beetles than traps painted green, red, dark blue, or black. These results are similar to those of Furlan (1996), who showed that yellow or white sticky traps collected more click beetles (*Agriotes ustulatus* Schäller) than red, black, or green traps. Other phytophagous Coleoptera show a preference for yellow over other colors (Fleming *et al.* 1940; Cross *et al.* 1976). We also showed that more *L. canus* were collected in traps set at 0.3 m and 0.9 m than at 1.5 m above ground (Figs. 2-3). Boiteau *et al.* (2000) used interception traps to collect over 40 species of Elateridae, and noted that trap catch decreased with increasing height of the traps. The exact relationship between trap height and trap catch varied with species. Furlan (1996) showed that sticky traps placed just above the tops of vegetation collected more *A. ustulatus* than traps at higher elevations.

Lastly, almost all of the females collected at the beginning of their flight period had been mated (at least 36 of the 39 females that were dissected contained sperm or a spermatophore). *Limonius canus* evidently mates soon after emergence in spring, as noted for the congeneric *L. californicus* (Stone 1935, 1941). Click beetles in other genera also mate soon after emergence from the soil (Cohen 1942; Zacharuk 1962). In *C. destructor*, the female may be mated while still below the soil surface (Zacharuk 1962). However, because we do not know the age of the females that were trapped in this study (i.e., we have no data on emergence), and because we do not know the amount of time between the day that a female was mated and the day that she was trapped, we cannot say when, following emergence from the soil, mating occurred. Begg (1962) showed that female *Limonius agonus* was most dispersive relatively late in the oviposition period, and it may be that *L. canus* has a similar life history. If so, the female beetles that we collected may have been mated long before being trapped.

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REFERENCES

Becker, E.C. 1958. The phyletic significance of the female internal organs of reproduction in the Elateridae. Proceedings of the Tenth International Congress of Entomology (vol. 1): 201-205.

Begg, J.A. 1962. The eastern field wireworm, *Limonius agonus* (Say) (Coleoptera: Elateridae), in southwestern Ontario. Proceedings of the Entomological Society of Ontario 92: 38-45.

Boiteau, G., Y. Bousquet and W. Osborn. 2000. Vertical and temporal distribution of Carabidae and Elateridae in flight above an agricultural landscape. Environmental Entomology 29: 1157-1163.

Cohen, M. 1942. Observations on the biology of *Agriotes obscurus* L. I. The adult insect. Annals of Applied Biology 29: 181-196.

Crocker, R.L., M.G. Klein, X. Wei and W.T. Nailon, Jr. 1999. Attraction of *Phyllophaga congrua*, *Phyllophaga crassissima*, *Phyllophaga crinita*, and *Cyclocephala lurida* (Coleoptera: Scarabaeidae) adults to selected volatile compounds. Southwestern Entomologist 24: 315-319.

Cross, W.H., H.C. Mitchell and D.D. Hardee. 1976. Boll weevils: response to light sources and colors on traps. Environmental Entomology 5: 565-571.

Doane, J.F. 1961. Movement on the soil surface, of adult *Ctenicera aeripennis destructor* (Brown) and *Hypolithus bicolor* Esch. (Coleoptera: Elateridae), as indicated by funnel pitfall traps, with notes on captures of other arthropods. Canadian Entomologist 93: 636-644.

Doane, J.F. 1963. Dispersion on the soil surface of marked adult *Ctenicera destructor* and *Hypolithus bicolor* (Coleoptera: Elateridae), with notes on flight. Annals of the Entomological Society of America 56: 340-345.

Fleming, W.E., E.D. Burgess and W.W. Maines. 1940. Relation of color to the effectiveness of Japanese beetle traps. Journal of Economic Entomology 33: 320-327.

Furlan, L. 1996. The biology of *Agriotes ustulatus* Schäller (Col., Elateridae). I. Adults and oviposition. Journal of Applied Entomology 120: 269-274.

Gibson, K.E. 1939. Wireworm damage to potatoes in the Yakima valley of Washington. Journal of Economic Entomology 32: 121-124.

Gough, H.C. and A.C. Evans. 1942. Some notes on the biology of the click beetles *Agriotes obscurus* L. and *A. sputator* L. Annals of Applied Biology 29: 275-279.

Iwanaga, S. and F. Kawamura. 2000. Trapping efficiency of funnel-vane and water pan traps baited with synthetic sex pheromone of the sugarcane wireworms, *Melanotus sakishimensis* Ohira and *M. okinawensis* Ohira (Coleoptera: Elateridae). Applied Entomology and Zoology 35: 283-285.

Jansson, R.K. and D.R. Seal. 1994. Biology and management of wireworms on potato, pp 31-53. In: G.W. Zehnder, M.L. Powelson, R.K. Jansson and K.V. Raman (Eds.). Advances in Potato Pest Biology and Management. APS Press, St. Paul, MN.

Lafrance, J. 1963. Emergence and flight of click beetles (Coleoptera: Elateridae) in organic soils of southwestern Quebec. Canadian Entomologist 95: 873-878.

Landis, B.J. and J.A. Onsager. 1966. Wireworms on irrigated lands in the west: how to control them. Farmers' Bulletin 2220. USDA, Washington D.C. 14 pp.

Lane, M.C. and M.W. Stone. 1960. Wireworms and their control on irrigated lands. Farmers' Bulletin 1866. USDA, Washington D.C. 19 pp.

Metzger, F.W. and R.J. Sim. 1933. Coleoptera captured in Japanese beetle traps. Journal of Economic Entomology 26: 296-297.

Onsager, J.A. 1975. Pacific coast wireworm: relationship between injury and damage to potatoes. Journal of Economic Entomology 68: 203-204.

Roebuck, A., L. Broadbent and R.F.W. Redman. 1947. The behaviour of adult click beetles of the genus *Agriotes* (*A. obscurus* L., *A. lineatus* L., and *A. sputator* L.). Annals of Applied Biology 34: 186-196.

Shirck, F.H. 1939. Observations on the flight of adults of the sugar-beet wireworm, *Limonius californicus* (Mann.). Journal of Economic Entomology 32: 726.

Shirck, F.H. 1942. The flight of sugar-beet wireworm adults in southwestern Idaho. Journal of Economic Entomology 35: 423-427.

Stone, M.W. 1935. Technique for life-history studies of wireworms. Journal of Economic Entomology 28: 817-824.

Stone, M.W. 1941. Life history of the sugar-beet wireworm in southern California. USDA Technical Bulletin 744. Washington D.C. 87 pp.

Toba, H.H. 1986. Wireworm control - then and now. Proceedings Washington State Potato Conference and Trade Show (1986): 97-103.

Toba, H.H. and J.E. Turner. 1983. Evaluation of baiting techniques for sampling wireworms (Coleoptera: Elateridae) infesting wheat in Washington. Journal of Economic Entomology 76: 850-855.

Williams, L., III., D.J. Schotzko and J.P. McCaffrey. 1992. Geostatistical description of the spatial distribution of *Limonius californicus* (Coleoptera: Elateridae) wireworms in the northwestern United States, with comments on sampling. Environmental Entomology 21: 983-995.

Zacharuk, R.Y. 1958. Structures and functions of the reproductive systems of the prairie grain wireworm, *Ctenicera aeripennis destructor* (Brown) (Coleoptera: Elateridae). Canadian Journal of Zoology 36: 725-751.

Zacharuk, R.Y. 1962. Distribution, habits, and development of *Ctenicera destructor* (Brown) in western Canada, with notes on the related species *C. aeripennis* (Kby.) (Coleoptera: Elateridae). Canadian Journal of Zoology 40: 539-552.