9-1-1975

False Wireworms of Economic Importance in South Dakota (Coleoptera: Tenebrionidae)

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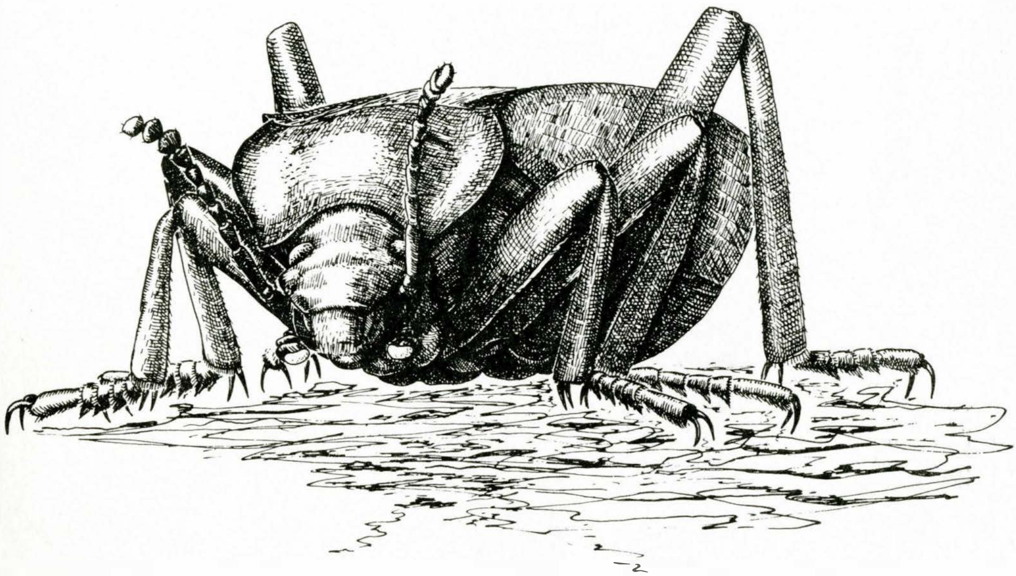

False Wireworms
of economic importance in South Dakota

Abstract

Seven species of false wireworms were found associated with grain crops in South Dakota. *Eleodes opaca* (Say) was the most abundant species and was frequently associated with damage to wheat fields. The larval stages of this species, *Eleodes extricata* (Say), and *Eleodes obsoleta* (Say) were present both during the spring and the fall and were capable of causing damage to recently sown grain fields at each of these times. *Eleodes suturalis* (Say) and *Eleodes hispilabris* (Say) were present in the actively feeding stage only during the fall and were capable of causing damage to winter wheat. *Embaphion muricatum* Say and *Eleodes tricostata* (Say) were present in grain fields but were not associated with damage.

In the past, summer fallow and crop rotation interrupted the life cycles of these species and kept populations below economic levels. However, changes in cropping practices in recent years have resulted in widespread damage. Continuous growth of wheat will increase the populations of false wireworms and may result in these insects being a limiting factor in wheat production.

On the cover: An adult *Elodes suturalis* beetle.

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False wireworm is the common name for larvae of beetles of the genera *Eleodes* and *Embaphion*. They belong to an extensive coleopteran family, Tenebrionidae, which has more than 15,000 described species and subspecies of which 210 belong to the genus *Eleodes* and 7 belong to the genus *Embaphion* (3).

The common name is derived from the fact that the larvae closely resemble larvae of Elateridae, the true wireworms. They can be distinguished from true wireworm larvae by several taxonomic characteristics. However, the easiest methods for field identification include: longer and more prominent legs, longer antennae that are conspicuously clavate, a non-flattened body, and more rapid movement of the larvae (16).

False wireworms are generally described as inhabiting the arid and semi-arid portions of the United States west of the 97th meridian. The adults are usually crepuscular or nocturnal and seek shelter during the day under litter, rocks and dried animal dung, and in small animal burrows. They feed on seeds, plant leaves, chaff, and occasionally soft bodied insects. They deposit their creamy white, oval eggs about 1/8 to 1/2 in. below the soil surface. The larvae, for the most part, exist below the soil surface where they feed on seeds, roots, and decaying organic matter.

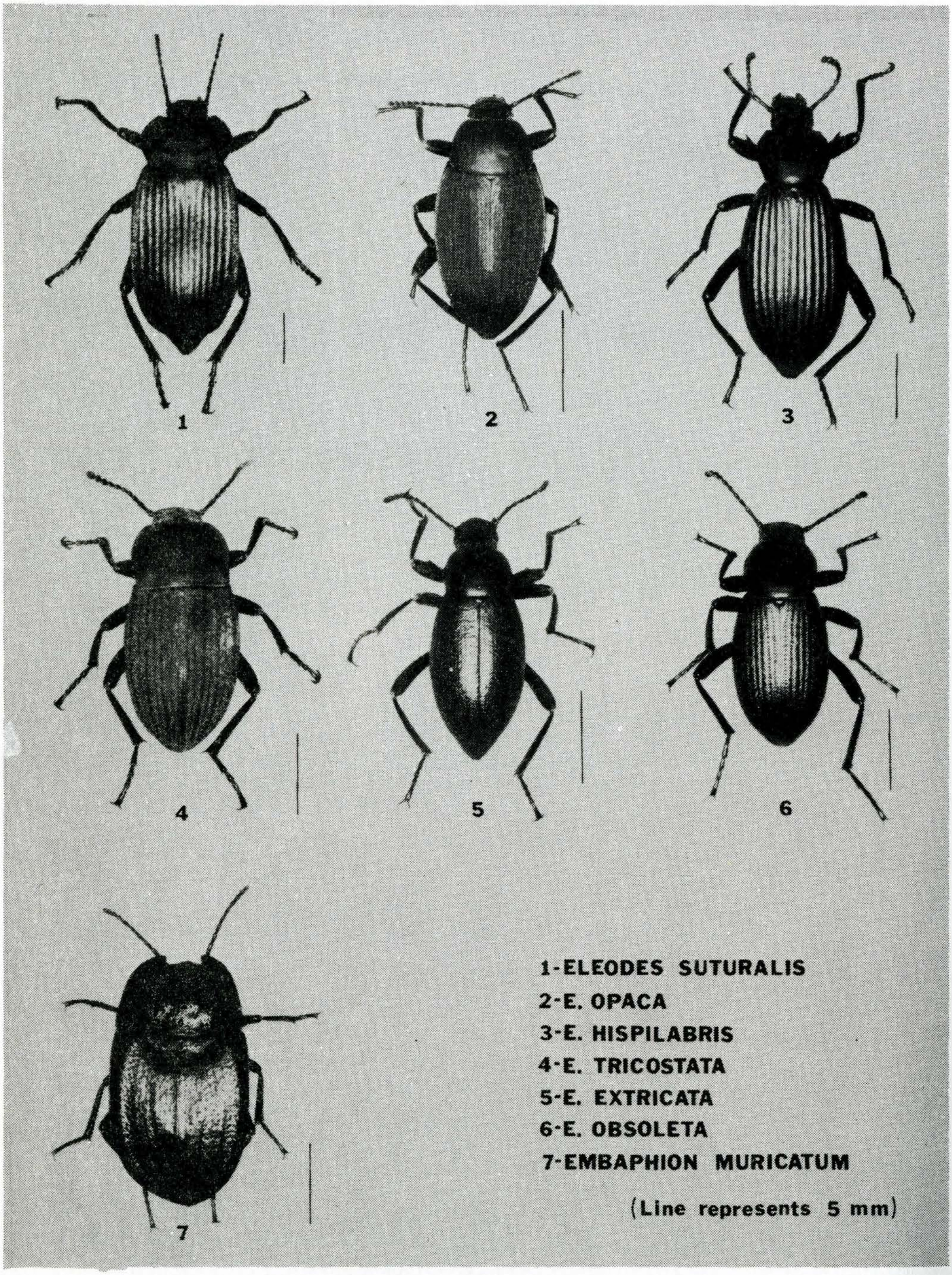

Fig. 1.--Dorsal aspect of adults of the 7 species of economic false wireworms found in South Dakota.

False wireworms were important pests of wheat during the early part of this century, and the cropping practices of that time were synchronized with the life cycle of several species. However, a widespread change in cropping practices occurred during the 1920s and 1930s. Farmers began to alternate wheat with other crops, and they began a practice called summer fallowing.

These practices were detrimental to false wireworms because they broke the crop continuity necessary for the completion of the life cycles. The economic importance of false wireworms seemed to decline quite sharply, and the mention of economic infestations no longer appeared in the scientific literature.

The recent occurrence of several scattered infestations prompted another look at this group of insects to determine the cause of these outbreaks and to ascertain what potential exists for another major problem to arise.

Biology and Life History

After extensive sampling of various habitats, seven species of false wireworms associated with crops in South Dakota were identified. These were *Eleodes suturalis* (Say), *Eleodes opaca* (Say), *Eleodes hispilabris* (Say), *Eleodes extricata* (Say), *Eleodes tricostata* (Say), *Eleodes obsoleta* (Say), and *Embaphion muricatum* Say (Fig. 1). Biology and life history information about these species have been accumulated by entomologists since 1890. Our studies were designed to use this early information to delve deeper into the ecology and the crop-insect relationships of these false wireworms in South Dakota.

Adults of each species were collected throughout western South Dakota for establishment of laboratory colonies and use in biological studies. The essential aspects of the biology of each species were determined by using the same standardized methods.

The separation of male and female beetles of each species was achieved by the use of criteria described by Blaisdell (3) (Table 1). The fecundity of females and the size of eggs were determined by the techniques developed by Matteson (17, 18).

The number of larval instars was determined from head capsule measurements with an ocular micrometer. The head capsules of neonates were measured, and the larvae were placed in small petri dishes containing ground wheat. The dishes were placed in plastic bags containing moist paper towels to prevent desiccation of the larvae and were held at constant temperatures of 21-24°C. Larval head capsules were measured daily, and the ground medium was examined for exuvia to determine the number of instars. Dyar's Law (11) was applied to assure that all instars were accounted for. Mature larvae and prepupae were placed in moist, sandy soil for pupation and held in cabinets at 24-47°C. The pans were examined daily for adult emergence. Newly emerged adults were placed in oviposition containers to determine the length of the preoviposition period. The oviposition medium was examined daily for the presence of eggs.

Table 1.--Distinguishing characteristics separating male and female false wireworm adults (3).

Species	Sexual characters Male	 Female
Eleodes suturalis	Prothoracic femora with acute tooth.	Prothoracic femora with a small obtuse tooth.
E. opaca	Body moderately narrow and fusiform.	Body broadly fusiform oval.
	1st 2 joints at prothoracic tarsi slightly widened and clothed beneath with dense pads of spongy pubescence, surface of pads flat.	Prothoracic tarsi unmodified.
E. hispilabris	Prothoracic femora with an acute tooth.	Prothoracic femora with an obtuse tooth.
E. tricostata	Elytra widest at base.	Elytra widest at middle.
	Abdomen distinctly impressed at base of 1st segment and between the coxae.	Abdomen strongly convex.
	Anterior spur of prothoracic tibia 1/3-1/2 longer than posterior.	Anterior spur of prothoracic tibia 2 times as long as posterior.
	1st joint of each prothoracic tarsus with a small, subacute tuft of yellowish pubescence on the produced tip beneath.	1st joint of prothoracic tarsus with a tuft of ordinary piceous spinules on the thickened tip.
E. extricata	Body fusiform-ovate, elongate.	Body ovate, rather robust.
	Prothoracic femora armed with subacute tooth.	Prothoracic femora unarmed.
	1st joint of prothoracic tarsi clothed at tip beneath, with a small subtruncate tuft of golden pubescence usually darkly discolored.	1st joint of prothoracic tarsi narrowly and transversely thickened at tip beneath with short piceous spinules.

Table 1. Continued.

Species	Sexual characters: Male	Sexual characters: Female
E. obsoleta	Body elongate.	Body robust.
	Elytra gradually narrowed posteriorly.	Elytra broadly oval and slightly narrowed posteriorly.
	Anterior spurs of prothoracic tibia ca. twice as long as posterior.	Anterior spurs of prothoracic tibia usually ca. 1/3-1/2 longer than posterior.
	1st joint of prothoracic tarsi with minute tuft of modified spinules scarcely evident, ordinary spinules present on thickened tip beneath.	1st joint of prothoracic tarsi with ordinary spinules on thickened tip beneath.
Embaphion muricatum	Abdomen moderately convex and not noticeable impressed.	Abdomen rather strongly convex.
	Prothoracic tibia quite suddenly and briefly constricted at base.	Prothoracic tibia gradually narrowed at base.

To determine the seasonal appearance of the stages of each species, it was necessary to make detailed observations in the field. Populations of adults were easiest to sample over wide areas because they moved about on the surface and could be easily trapped.

Other stages occurred in the soil in relatively low numbers and were quite difficult to sample systematically over large geographical areas. The temporal occurrence of these other stages was determined by sampling in areas of damage and at randomly selected sites throughout the growing season as well as by extrapolating the rate of development of each stage beginning with the appearance of reproductively mature adults.

To determine the seasonal appearance of adults throughout South Dakota it was necessary to collect them every 1 to 2 weeks throughout the growing season. Adults of false wireworms are flightless and exhibit a crepuscular or nocturnal activity pattern, making them difficult to find during the day.

To sample the populations adequately, two types of pitfall traps were used. One type consisted of 1-pt. mason jars as described by Matteson (17, 18). Another type, a trough trap designed to capture

larger samples, was constructed from galvanized metal and measured about 36 X 4 X 2 in. (6). Both types of traps were buried flush with the soil surface, and all vegetation and obstacles were cleared from a 6-in. band around each trap.

The jar traps were used in 1964, 1965, and 1966, and the trough traps were used in 1967 and 1968.

Traps were placed in grain fields on high level areas or at the crest of knolls about 20 ft. into the field in groups of three, usually 5-10 ft. apart. Many workers have indicated that false wireworms were most numerous in such locations (6, 21, 27, 29, 32).

Approximately 32 fields were selected each year as trapping sites within wheat growing areas of the state. Trapping periods and field locations varied from year to year because of cropping sequences. Fields used were either under summer fallow or crop rotation systems. Harvesting and weed control practices resulted in premature termination of some trapping sites, however.

Traps were visited at intervals of from 6 to 14 days. Beetles were usually found alive, but if they had died, the elytra were always present so that accurate identification and counts could be made.

Because the number of field locations and the time that traps were present at each site were variable within and among years, all of the data were reduced to the number of beetles caught per location per day. For ease of interpretation, the season was divided into 15-day intervals. The data were transformed to percentages of beetles of each species caught during each time interval throughout the 5-year period. This reduced the bias introduced by having unequal numbers of field sites and by extremes of daily weather effects.

Our experimental data and the observations of other entomologists are summarized in Table 2, which encompassed most of the pertinent details of the life cycle of these seven species. The number of instars and the mean head capsule widths of six of the species are shown in Table 3.

Table 4 shows the seasonal appearance of adults of each species from April 16 to October 15 from 1964 through 1968. The seasonal occurrences of the life stages of each species (from our studies and observations by other workers) are shown in Table 5. These combined observations complete the life histories of these seven species in South Dakota and illustrate how the seasonal appearance of each stage varied between species.

Table 2.--Biology of false wireworms found in South Dakota.[1/]

	Egg	
Species	Size range (LxW, mm)	Incubation period (days)
Eleodes suturalis	1.20-1.33 X 0.68-0.76 1.5- 2 X 1[h/] 1.2-1.37X0.63-0.77[b/]	7-26 (30-15°C) 8-10[h/]
E. opaca	1.20-1.32 X 0.65-0.73 1.1-1.4 X 0.50-0.65[d/] 1.5-1.7 X 8-0.85[e/]	u 6-9 6-19[d/] 6-10[f/]
E. hispilabris	1.10-1.32 X 0.65-0.75 1.5[a/]	10-12 9-13[a/] 14.91[i/] 10-18[i/]
E. tricostata	2.0-2.91 X 1.1-2.0 2.2-2.5 X 1.2[c/]	10 14.5 Av[c/] 6-11 Aug[c/] 46 Nov[c/]
E. extricata	0.9-1.4 X 0.60-0.75	8-10 10.86[i/]
E. obsoleta	1.7-2.3 X 0.98-1.33	8
E. muricatum	1.20-1.35 X 0.65-0.78 1.1-1.3 X 0.60-0.62[g/]	4-9 10-13[g/]

Table 2.--Continued.

Species	Larva: No. instars	Larva: Larval period (days)	Prepupa: Prepupal period (days)	Pupa: Pupal period (days)
E. suturalis	6[h] 11[b]	120 110-130[h] 40-50[b]	6 4-10[h]	17 10-22[h] 14-21[b]
E. opaca	12 11[d] 11[f]	60-80 300-350[f]	6 7[f]	9.6-20.6[d] 11-12[e] 8-20[f]
E. hispilabris	6-8[a] 11[i]	369[i]	4-8 4-6[a]	10 33.59[i] 13-79[i] 15-20[a]
E. tricostata	Unknown	280[c]	5-10[c]	18.45[c]
E. extricata	11[i]	79-96 367[i]	14	14-17[b] 11.4m[i]
E. obsoleta	9	151.7	6.8	19.9
E. muricatum	14	76 79[g]	4 7-9[g]	13.4 18-20[g]

Table 2.--Continued.

Species	Adult			
	Preovi-position period (days)	Total no. eggs	No. eggs/♀ per day	Total adult life (days)
E. suturalis	26-29h/	108 avh/ 335 maxh/	29.13 14-20b/	200-600
E. opaca	10-20d/ 28-42f/	389+d/ 25-400f/	5.3d/ 7-8f/	90-100 60-120d/ 60-90f/
E. hispilabris	20-30 250i/	Unknown	17.7	360 300i/ 240-480i/
E. tricostata	Unknown	176 avc/	2.0 3.7c/	90-120 330-390c/
E. extricata	21	Unknown	3.47	60
E. obsoleta	Unknown	Unknown	2-4	60
E. muricatum	10-14	230+	5.36	90-120

1/ Data with no citation are results of this study.

a/ Haverfield (15)
b/ Matteson (17,18)
c/ McColloch (19)
d/ McColloch (20)
e/ Swenk (25)
f/ Swenk (26)
g/ Wade and Boving (28)
h/ Wade and St. George (29)
i/ Wakeland (32)

Table 3. Number of instars and average head capsule widths of false wireworms found in South Dakota.

Instar	Mean head capsule width (mm)					
	E. suturalis[a/]	*E. opaca*	*E. hispilabris*	*E. extricata*[c/]	*E. obsoleta*	*E. muricatum*
1	0.40	0.41	0.40	0.39	0.58	0.40
2	.46	.49	.47	.43	.69	.50
3	.61	.56	.60	.50	.80	.60
4	.85	.63	.74	.60	.96	.70
5	1.15	.71	.85[b/]	.72	1.16	.80
6	1.53	.81[b/]	1.02[b/]		1.38	.92
7	2.07	.91[b/]	1.21		1.64	1.04
8	2.73	1.05[b/]	1.44		2.00	1.18
9	3.23	1.20	1.71		2.21	1.34
10	3.71	1.36	2.10			1.51
11	4.28	1.50	2.45			1.71
12		1.64	2.87			1.86
13			3.43			1.98
14						2.10

a/ Matteson (17). b/ Calculated means. c/ Incomplete

Table 4. Seasonal appearance of false wireworm adults in pitfall traps in South Dakota. 1964-1968.

	Percentage of total beetles of each species trapped each 15-day period											
	April	May		June		July		August		Sept.		Oct.
	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	1-15
Eleodes suturalis	0.4	0.2	2.7	8.3	15.6	20.6	19.6	16.4	6.9	4.1	3.0	2.3
E. opaca	0	0	0	0.7	4.9	10.6	16.0	18.7	25.8	17.8	5.4	0
E. hispilabris	0	0	0.8	4.6	4.1	5.0	7.7	12.5	21.8	20.7	18.3	4.6
E. tricostata	0	0	.9	3.7	4.6	7.0	23.3	25.2	19.2	12.6	3.3	0.2
E. extricata	0	0	0	0	0	0	2.1	22.9	34.1	14.6	17.3	8.9
E. obsoleta	0	0	.4	.2	0.1	0.5	4.2	13.8	26.0	27.2	24.3	3.4
Embaphion muricatum	.1	1.2	4.1	7.7	13.1	29.3	19.7	9.1	6.4	3.7	4.5	1.2

Table 5. Seasonal occurrence of eggs, larvae, pupae, and adults of false wireworms.

Species	Egg	Larva	Pupa	Adult	Overwintering stage
Eleodes suturalis	Spring-late summer[i]	All seasons[i]	Spring-late summer[i] Spring and early summer[c]	All seasons[i] June-Sept.[f]	Adult[i] Larva[i] 10th instar[c] Mature larva[g]
E. opaca	July-Oct.[e,f,g]	Aug.-May[g]	April and May June[e] May-July[g]	May-Oct.[e] June-Sept.[g]	Larva Mature larva[e,g]
E. hispilabris	Spring[j] May and June[k] May-Nov.[b]	Aug.-June[k]	July[k]	May-Oct. June-July[f] July-Aug.[j] Aug.-June[k]	Larva[b,k] Adult[b,k]
E. tricostata	July-Oct.[d]	July-June[d]	May-July[d]	May-Oct. June-Nov.[d]	Adult[d,e] Next to last instar[e]
E. extricata	Fall	June-May[k]	June-July[k]	July[k] July-Oct.	Adult and Larva[j]
E. obsoleta	Aug.-Oct. Aug.-May[a]	May[a]	June[a]	May-Oct. Aug.-Oct.[a]	Larva Egg[a]
Embaphion muricatum	May-June[h]	June-Apr.[h]	May[h]	June-May[h]	Adult and mature larva[h]

a/ Blumberg (4)
b/ Haverfield (15)
c/ Matteson (17,18)
d/ McColloch (19)
e/ McColloch (20)
f/ McColloch (21)
g/ Swenk (26)
h/ Wade and Boving (21)
i/ Wade and St. George (29)
j/ Wakeland (30)
k/ Wakeland (32)

Eleodes suturalis

Complete taxonomic and morphological descriptions of all stages of this species were given by Wade and St. George (29). It overwintered as an adult under straw, grass, weeds, and refuse and as a mature larva deep in the soil.

Adults emerged in early spring and laid 14-20 eggs/day in the soil throughout the summer and fall. Eggs measured 1.2-1.37 mm X 0.63-0.77 mm (17). The incubation period in the field was 8-10 days but varied according to moisture and temperature regimes. Early growth and development were rapid and the larvae passed through several instars in a few weeks. Matteson (17) established that 11 instars normally occurred. The larval period from 1st to 10th instar lasted 40-50 days at 80°F. During the 10th instar, the larvae required exposure to temperatures of 40°F for at least 60 days to break an obligatory diapause (17, 18). This requirement corresponded to the winter period and allowed this species to overwinter. After the winter cold period, the larvae resumed feeding for a short period, molted once more, constructed earthen cells, and entered the prepupal stage which lasted about 6 days. The pupal stage lasted from 10 to 22 days.

Upon emergence from the pupal cells, adults were inactive until the exoskeleton hardened. Mating occurred 6-7 days after emergence, and the first eggs were deposited 20 to 22 days later. An average of 29 eggs/day were deposited over several weeks. The longevity of adults exceeded 2 years in the field but seldom exceeded 1.5 years in the laboratory.

Adults were trapped during each 15-day interval throughout the sample periods. Those appearing in late April probably overwintered as adults. Young adults, as evidenced by a brighter, deep glossy appearance, began appearing in the traps near the end of May. The preoviposition period was found to be about 28 days. The first eggs from young adults were deposited near the end of June, and oviposition continued until September. Larvae from eggs laid by the overwintered adults and the earliest eggs deposited by the new generation adults reached the 10th instar before September.

Mature larvae normally did not pose a threat to fall-seeded grains because feeding at that stage was insignificant (17, 18). Larvae in the 4th-6th instars, which had hatched from eggs deposited in August, fed actively and posed the greatest threat to fall-seeded grains. They probably did not reach the 10th instar until fall, but because of the diapause phenomenon, almost all larvae were in the same stage of growth when cold temperatures occurred. The highest number of adults was caught during July (the month of harvest); peak oviposition occurred during August and early September.

There were usually numerous seeds scattered over the ground during harvesting, and these served as food for both adults and newly hatched larvae for several weeks. The life history of this species was synchronized with the planting dates of winter wheat in such a way

that these insects posed a serious threat. They probably did not threaten spring-seeded grains because the larvae present in the spring were about to pupate.

Eleodes opaca

Adults were commonly found in the field from mid-June to mid-September and reached their greatest abundance in eastern Nebraska during late July and about 15 days later in western Nebraska (26). In South Dakota, the peak adult emergence occurred during late August. Adults lived for 2 to 3 months as determined by mark-and-recapture (6), but they occasionally survived as long as 4 months (26).

Adults began mating 4 to 6 weeks after emergence and oviposition commenced a few days later. The oviposition period lasted from 2 to 8 weeks. The number of eggs each female produced per day during the period of egg laying ranged from 2 to 8 and averaged 5.3 (20). The total number of eggs laid by each female varied from 25 to 400 but averaged about 100. The size of eggs ranged from 1.2 to 1.32 mm X 0.65 to 0.73 mm. Eggs were deposited from early July to October, but primarily during August and September (26). The incubation period varied with temperature; eggs deposited in mid-summer hatched in 6-10 days and those deposited in the fall took up to 19 days to hatch (20).

Some difficulty was experienced in rearing larvae of *E. opaca* on ground wheat in the absence of soil. Only 5 instars were completed under these conditions (Table 3). Additional head capsule measurements were made from larvae from the laboratory colony. By using Dyar's Law to determine what instars were missed in our examinations, it appeared that this species had 12 instars; instars 6, 7, and 8 were not observed. The larvae took from 60 to 80 days to complete development in soil in the laboratory. The average time spent in the larval stage under field conditions was 318 days (20, 26). However, this included the 199-day overwintering period.

Early larval growth was rapid, which allowed partly grown larvae to be present during the fall seeding of winter grains. There was a period of very slow growth during the 5th stadium. The timing of this slower development coincided with the onset of cold temperatures. This phenomenon was apparently not an obligatory diapause because the species could be reared successfully at constant warm temperatures. However, this slow growth stage and cold temperatures occurred simultaneously, so a diapause was not necessary to synchronize the development of the population. Also, no adults were found before June 1 and only a few were present before July 1. Thus, additional larval growth occurred in the spring. Larvae have been observed feeding on and damaging seeds and seedlings in grain fields in April and May. The prepupal stage lasted 7 days. The pupal stage required from 9.6 to 20.6 days to complete. Pupation began in western Nebraska about mid-May and pupae were commonly found during May, June, and July (26). The timing was about 20-30 days later in west-central South Dakota.

Because larval feeding occurred in both the fall and the following spring, this species posed a threat to both fall- and spring-seeded grains.

Eleodes hispilabris

Adults overwintered almost entirely in waste areas and were often found in burrows of small mammals (31). Eggs were deposited singly in loose soil during late May and early June. The egg measurements ranged from 1.1 to 1.32 X 0.65 to 0.75 mm. The eggs hatched in 9-13 days (15); however, Wakeland (31) reported that the incubation period averaged 14.91 days.

Difficulty was encountered in rearing larvae in petri dishes on ground wheat where the number of molts could be detected easily. Therefore, it became necessary to remove larvae from soil periodically to measure head capsules. The head capsule width measurements tended to cluster around certain means. When ratios between adjacent means were calculated, the ratios were relatively constant, which were in accordance with calculations proposed by Dyar (11) for detection of all larval instars of lepidopteran larvae.

This species had 13 instars. Larvae in rearing containers developed from egg to the 12th instar in about 4 months. At that time, they appeared to require a cold treatment of 2 months similar to that for *E. suturalis*. However, occasionally, when we transferred mature larvae to fresh soil in preparation for placing them in the cold room, a pupa would be discovered, which led to doubts about an obligatory diapause.

To determine whether these larvae had an obligatory diapause or merely a facultative one, we periodically placed pans containing about 200 mature larvae at 27°C for an additional 2 months to determine whether all larvae would pupate. About 5% of all larvae entered the pupal stage without undergoing a cold treatment.

When larvae were returned to 27°C after being held at 4°C for 60 days, they molted once more and entered the prepupal stage which lasted 4-8 days. The pupal stage required 15 to 20 days (15). Adults began laying eggs 3-4 weeks after emergence. Initially, egg production was low, but it soon began to increase. At the peak, the number of eggs deposited by each female was 17.7 per day. The total number of eggs produced during an average adult lifetime was not determined; however, females appeared to continue laying eggs throughout most of their life. The laboratory longevity of both laboratory-reared and field-collected adults was about 1 year.

Adults emerging from pupal cells in August lived until the following year. They began laying eggs during May and continued until their death. Larvae that hatched in June fed and developed throughout the summer and became nearly full grown by fall. They overwintered as larvae and pupated during July. Thus, two generations overwintered simultaneously, one in the larval stage and the other in the adult stage (15, 30, 31, 32).

Larvae continued feeding in the fall until they reached maturity or until cold temperatures stopped all activity. If populations were high enough, economic damage occurred. Those larvae that had not reached maturity in the fall continued feeding the following spring

and posed a threat to crops sown in the spring in those fields. In the past, this species caused about 10% loss to the wheat crop in Idaho (32).

Eleodes tricostata

Eggs deposited by females in the field from mid-July to mid-November varied in size from 2.2 to 2.9 mm X 1.1 to 2.0 mm and so were considerably larger than eggs of the other six species. The average production was 3.7 eggs/female per day and 176 eggs/female per lifetime. The largest number of eggs produced by a single female in 24 hr. was 51. The incubation period varied with temperature: 6 to 11 days were required in July and August, and as many as 46 days were needed in November.

Considerable trouble was experienced in rearing larvae. None lived for more than a few days on ground wheat, and no large larvae were produced in soil in the laboratory. Consequently, no instar measurements or total number of instars could be determined for this species.

Adults were first captured in late May. However, population levels remained low until late July and August. The sudden population increase undoubtedly resulted from the emergence of young adults. The population remained relatively high until late September when it declined quite drastically. The life cycle of this species resembled the life cycle of *E. opaca* except that the larvae almost reached maturity in the fall and probably did not have a lengthy feeding period during the following spring.

A few adults overwintered. However, eggs were never obtained from these overwintered females. Females seemed to outlive males (19).

Because the larval stage of this species was only found intermittently in cropland though it was common in native grassland (19), it was not expected to be a threat to wheat crops in South Dakota.

Eleodes extricata

The eggs of *E. extricata* ranged in size from 0.9 to 1.4 X 0.6 to 0.75 mm. At 29°C, incubation time was 8 days; at 24°C, it was 10 days. The larvae did not grow or develop well on ground wheat: they were only maintained until the 5th instar. They did quite well in soil; however, the number of instars could not be determined precisely because so few were available and because they were sensitive to frequent handling which contributed to a high rate of mortality.

Wakeland (32) determined that there were 11 instars. In soil, larvae took from 79 to 96 days to reach the prepupal stage, and the prepupal period was 7 to 21 days. Pupae only occurred during June and July (18, 32). The preoviposition period of newly emerged adults was 21 days. Adults laid about 31.5 eggs/day for extended periods. Adults collected from the field did not live more than 2 months.

No adults were captured until late July. The adult population peaked in late August and declined rapidly thereafter. Adults did not appear to overwinter as indicated by these trap catches. Eggs were deposited during August and September. Partly grown larvae overwintered and resumed growth and feeding the following spring.

Since feeding occurred during both the fall and spring, this species would pose a threat to fall and spring grains if populations were sufficiently high.

Eleodes obsoleta

Adults laid about 2-4 eggs/day for 1.5 months. The egg size ranged from 1.7 to 2.3 X 0.98 to 1.33 mm, and the incubation period was 8 days at 24°C. There was an average of 9 instars; however, a few larvae pupated after 8 instars and two developed 10 stadia before pupating. The average time spent in the larval stage was 151.7 days. The prepupal stage lasted 6.8 days, and the pupal stage lasted 19.9 days. The preoviposition period was not determined. The adult life in the laboratory was only 2 months.

Adults were first found in late May in very low numbers, and no substantial increase occurred until August. The population reached a peak in late August, remained high throughout September, and then dropped very drastically in October. The low numbers of adults in May indicated that a very few were able to overwinter. Adults collected from the field in August immediately began to lay eggs when brought to the laboratory. These eggs hatched in about 8 days and the young larvae began feeding immediately.

Blumberg (4) found that the adults of this insect lived only from early August to late October. Eggs were laid during August, September, and October and overwintered as such. He hypothesized that the larval stage began in May and ended in early June and that the pupae were present from June until August in Colorado. He observed only the adult stage in the field and was not able to rear the insect successfully in the laboratory. Therefore, his conclusions concerning the life cycle were only based on the seasonal appearance of the adults and the fact that larval forms appeared briefly in the laboratory at the end of May.

If this species overwintered in the egg stage (4), the eggs deposited throughout August and September would require a diapause to prevent hatching prior to winter. This diapause would be broken after exposure to cold temperatures much like the larval diapause of *E. suturalis*. Thus, this species obviously does not have an egg diapause in South Dakota.

Overwintering occurred in the partly grown larval stage. The larval period lasted for about 152 days in the laboratory. During the life cycle in the field, part of this active feeding stage took place in the fall and the remainder occurred in the spring. The pupal stage occurred during July.

This species had the capability of being present and potentially destructive both in the fall and in the following spring.

Embaphion muricatum

Wade and Boving (28) gave complete taxonomic and morphological descriptions of each stage of *E. muricatum*. The egg size ranged from 1.1 to 1.35 X 0.60 to 0.78 mm, and eggs were deposited during May and June in loose soil 1/2 - 1 in. deep, sometimes singly but more often in clusters of 2 to 12. The average period of incubation was 10 to 13 days at temperatures of 70 to 90°F.

The length of the larval stage ranged from 76 to 96 days. In the field, many larvae appeared to become nearly mature during late fall and overwintered in that form. The semidormant prepupal period that occurred in April lasted about 7 to 9 days. The pupal stage during May required 10 to 20 days.

Adults did not mate until a week or more after emergence. The average rate of oviposition was 5.36 eggs/female per day over a period of 29.7 days. Adult females were capable of ovipositing about 160 eggs during a 4-week period. The longevity of adults was about 12 months in the field.

Adults were captured during each 15-day interval that traps were operated but relatively few were trapped except during late June and throughout July. The appearance of beetles in the field early in the spring indicated that some adults overwintered. The oviposition period of several weeks and the absence of a diapause mechanism in the larval stage allowed larvae of several stadia to overwinter. Pupation probably occurred in May.

Larvae were present in both fall and spring, but because larval and adult stages occurred over such a long period, the impact of the population was not as great as if the actively feeding stages were all present during a short period. This species could be economically important if the population was high during critical periods.

Distribution

The distribution of an insect species is an integral part of its ecology and reflects the environmental conditions necessary for survival provided that distribution is not limited by the range of its hosts. This is especially true of species like false wireworms that have low mobility. In such species, distribution in relation to paedographic patterns is correlated more closely to those inhabiting the soil. Soil type differences that are important are related to porosity, structure, water holding capacity, or chemicals associated with a particular soil.

Distribution within a small area ranging from a few square miles to a few square inches is probably more closely related to the micro-

environmental parameters of the life cycle of the insect. Much of this type of distribution is related to topography which in turn influences temperature, soil moisture, and vegetation. A species thought to be adapted to a wide range of environmental factors may, in fact, be restricted to microenvironments that have relatively narrow parameters.

Topographic: The spatial and topographical distributions of four species of false wireworms within a winter wheat field were determined by Calkins and Kirk (6). *Eleodes suturalis* and *E. opaca* were both found more frequently near the tops of knolls but differed in their distribution on level portions of the field. *Eleodes opaca* was found in greatest numbers within the field, *E. suturalis* seemed to congregate along the field edges. *Eleodes tricostata* was found on the midslopes of hills and near the borders of the field. *Eleodes obsoleta* occupied both the middle and top portions of slopes as well as the field edge.

Each species appeared to have a different distribution within localized areas even though food habits, life cycles and larval habitats were similar. This apparent subdivision of the habitat reduced the competition for food, space, and contact between species.

Paedographic: False wireworms have been described as inhabitants of sandy or sandy loam soils. Soils containing high percentages of clay were supposedly not suitable for larval development (21, 27, 29). Frequent references to this close relationship have resulted in the generalization that these insects would not be of economic importance in heavier soils. However, several instances of damage by false wireworms in regions of clay, silt, and loam soils in South Dakota have cast doubts on this generalization.

In a detailed study, Calkins and Kirk (9) were able to assess the distribution of six species of false wireworms among the three major soil types (Table 6). *Eleodes suturalis* was found frequently in all three major soil types but most frequently in sandy soils. *Eleodes opaca,* the most abundant species, was found most frequently in sand and clay soils, while *E. tricostata* was recovered about equally in all soil types. *Eleodes obsoleta* was most abundant in sandy soils but was more abundant in loam than in clay soils; *E. hispilabris* and *E. muricatum* were abundant only in sandy soils. Thus, certain species were adapted to heavier soils and that these particular species were the ones responsible for damage in heavy clay areas.

Geographic (South Dakota): The geographic distribution of the seven species of false wireworms was determined for South Dakota by personal collections, from examination of museum specimens and records, and from information provided by former Plant Pest Control Division (now: The Animal and Plant Health Inspection Service), U.S. Department of Agriculture. These data were summarized by Calkins (4a) in the form of distribution maps for each species.

Eleodes suturalis, E. opaca, and *E. tricostata* were more widely distributed than the other four species. *Eleodes suturalis* and *E. tricostata* are about as widely distributed in the subhumid climate of

Table 6. Percentage of false wireworm beetles trapped in clay, loam, or sand soils in South Dakota, 1964-1968.[a/]

Species	% of beetles in each type of soil: Clay	Loam	Sand	Total no. beetles
E. suturalis	24 a	27 a	49 b	869
E. opaca	43 b	19 a	38 b	2690
E. hispilabris	4 a	47 b	49 b	114
E. tricostata	19 a	40 a	41 a	298
E. obsoleta	1 a	13 b	86 c	305
E. muricatum	1 a	47 b	52 b	182

a/ Numbers in the same row followed by the same letter are not significantly different from each other at the 5% level in Duncan's multiple range test.

eastern South Dakota as in the semiarid area of the western half of the state. The other species were much more common in the dry western portion; in fact, *E. extricata* was found only in that area.

Damage

False wireworms did the greatest injury during the fall, when rainfall was abnormally low. During dry periods, the seeds sometimes did not germinate for several weeks and were thus susceptible to injury for long periods. During years when sufficient moisture was available for rapid germination, less damage was apparent (29). The larvae attacked fall seeded grain immediately after planting and destroyed it before germination. A single larva working along a drill row was able to destroy several kernels (20, 26, 29). Damage to individual kernels ranged from the ends nibbled or the germ eaten to the entire seed consumed with only a thin shell remaining.

Damage often did not end when seeds germinated but continued until seedlings had established vigorous root systems. When populations of larvae were extremely high, intensive feeding frequently damaged young plants that were several inches tall (20, 23, 29). Damage occurred when larvae feeding on the epicotyl cut the plants off just above the seed.

Infestations in the fall were often found spreading from the tops of knolls, thus giving the fields a spotted appearance. These areas were usually the driest parts of the fields, and the wheat planted there was susceptible to feeding damage because of slow germination and higher populations of insects (6).

Adults have been observed feeding on wheat kernels scattered on the ground and even doing some injury to wheat heads in the "shock". Nevertheless, the adult stage was not regarded as economically important. In the past, however, adults attracted to shocks, straw piles, and accumulations of grain, congregated to feed and remained to lay eggs. Those areas were frequently the sites of intense larval damage to wheat the following year.

Fields that were most severely damaged had one or several things in common: (1) damage occurred in fields in the vicinity of straw stacks, shocks, or scattered bundles of grain; (2) weedy and trashy fields were heavily infested while fields with few weeds were not infested; (3) summer-fallowed fields where poor weed control was maintained harbored larvae that destroyed newly seeded wheat; (4) wheat planted on ground recently converted from pasture sod was severely damaged; (5) wheat planted in fields in which wheat was destroyed the previous year was again attacked; and (6) those fields in which wheat was grown consecutively for 2 or more years were invariably damaged (14, 16, 20, 23, 26, 27, 29, 32).

The percentage of loss caused by false wireworms was not easily determined because the injury was frequently confused with that caused by true wireworms, white grubs, fall armyworms, Hessian flies, and winter kill (20). Other workers have reported that farmers were not aware of damage during dry autumns until long after damage had occurred and the insects had vanished. They frequently attributed the damage to dry weather.

Damage usually occurred in large bare spots in the field, but in extreme cases, entire fields were destroyed. When plants were removed in a very discontinuous manner, however, the reduction in yield was not closely correlated to the reduction in numbers of plants because surrounding plants used the additional water, space, nutrients, and light to increase their yields. This was especially true when the supply of any one of these items was limited.

Therefore, false wireworms were economically significant when damage was continuous enough to produce significant gaps in the drill rows. Larvae tended to feed within drill rows where soil was more porous, thereby removing successive plants and creating such gaps.

Economic thresholds were not easily determined. Swenk (25) observed populations of 3-4 larvae of *E. opaca* per ft of drill row damaging 60% of the wheat kernels. We regularly observed that less than 1 larva per ft of drill row was associated with damage in fields in South Dakota. This probably is the closest estimate of an economic threshold available. B. H. Kantack, S. D. Extension entomologist, indicated that treatment recommendations in South Dakota were not based upon larval numbers but upon the appearance of damage (personal communication).

Hosts

Although false wireworms were most often associated with damage to wheat, they have also fed on and damaged oats, corn, rye, millet, alfalfa, and sorghum (29). In addition, they fed on seeds of wild grasses and herbs. Because no qualitative host range or food preferences have been established for false wireworms, we studied the preferences of *E. suturalis* and *E. muricatum* for seeds of native and introduced plants and evaluated the potential danger to newly seeded crops (5, 7).

Feeding preference tests of entire seeds were made in the laboratory with both adults and larvae. Planted seeds which germinated and became seedlings were evaluated in the greenhouse for feeding damage by larvae only.

The percentage of seeds damaged by adults and larvae in laboratory tests and by larvae in greenhouse tests are shown in Tables 7 and 8. When larvae and adults of *E. suturalis* were offered 34 types of seeds, both stages consumed almost all the seeds of hulless barley, hulless oats, wheat, forage sorghum, grain sorghum, sweetclover and rye. *Embaphion muricatum* preferred wheat, hulless oats, and rye. Seeds of introduced plants were more preferred in laboratory tests than seeds of native species.

Most of the crops tested were adapted to dryland conditions. The extent of damage to these crops depended upon the insect population present, the moisture level of the soil, and the previous year's crop. For example, corn and sugarbeets usually are grown under irrigation in dryland areas. Therefore, if these crops were planted in a field that had been in sod or small grain the year before, enough false wireworm larvae might be present to cause damage.

Control

Mechanical: Most of the mechanical control of false wireworms involved plowing to destroy pupae. Deep plowing in late July and August controlled many species in the Pacific Northwest (15). Late fall and early spring plowing reduced populations of *E. muricatum* in Kansas (27), and plowing in May destroyed most pupae of *E. opaca* (25). There is no mechanical control presently recommended for South Dakota.

Cultural: The cultural controls found most effective for suppression of false wireworms consisted of summer fallow, crop rotation, and weed control. The greatest injury occurred on land that was planted to wheat each year (19). Those fields that had been in row crops or were fallowed the previous year sustained little or no damage.

Summer fallowing practices normally began about one month after harvest. An implement was used that destroyed weeds by cutting the roots below the soil surface; thus the crop stubble remained to trap blowing snow during the winter. This disturbance of the soil destroyed many pupae and larvae.

Table 7. Percentages of seed of various plants eaten by larvae and adults of *E. suturalis* and *E. muricatum* in laboratory tests.[a]

	% seeds consumed by:			
	E. suturalis		*E. muricatum*	
Plant species	Larvae	Adults	Larvae	Adults
Hulless barley[b]	100	95	33	51
Hulless oats[b]	100	96	65	85
Wheat[b]	99	92	67	79
Forage sorghum[b]	98	85	35	55
Grain sorghum[b]	98	100	40	56
Sweetclover[b]	96	64	41	72
Rye[b]	92	73	56	89
Russian wild rye[b]	91	3	8	29
Smooth brome[b]	90	14	17	15
Alfalfa[b]	79	94	30	74
Flax[b]	76	93	9	15
Green foxtail[b]	75	16	45	52
Corn	71	45	21	36
Harding grass[b]	61	13		
Oats[b]	58	78	18	6
Crested wheatgrass[b]	53	13	15	9
Sudangrass[b]	43	14	1	11

Table 7. Continued.

Plant species	% seeds consumed by: *E. suturalis* Larvae	*E. suturalis* Adults	*E. muricatum* Larvae	*E. muricatum* Adults
Barley[b]	41	49	11	8
Switchgrass	38	7	7	4
Soybean[b]	36	9	1	2
Sand lovegrass	28	14	24	67
Side-oats grama	27	0	20	11
Western wheatgrass	23	1	3	1
Big bluestem	19	1	5	7
Plantain	19	34		
Green needlegrass	18	80	5	3
Kentucky bluegrass[b]	17	16	18	20
Johnsongrass[b]	14	2	4	10
Sand bluestem	8	0	3	1
Sugarbeet	8	3	0	3
Yellow foxtail[b]	6	14	3	4
Little bluestem	4	7	3	9
Goat's-beard	2	3		
Indiangrass	0	0	0	5

[a]Based upon 15 tests.

[b]Introduced species.

Table 8. Percentage of plants damaged by larvae of *E. suturalis* and *E. muricatum* in greenhouse tests[a].

	% loss of seeds and seedlings	
Crop species	*E. suturalis*	*E. muricatum*
Sugar beet	100.0	
Hulless oats	95.9	
Forage sorghum	94.9	
Grain sorghum	93.2	
Hulless barley	83.5	
Wheat	71.6	50.0
Rye	70.7	67.2
Flax	64.1	
Barley	57.2	24.1
Oats	54.5	20.4
Corn	39.2	
Soybeans	26.4	21.3

[a]Based upon 3 tests each with 6 replications.

During the spring the stubble was turned under, usually with a 1-way disc. This practice destroyed a large proportion of the remaining pupae and larvae at a time when most of the species were pupating and the pupal stages were very susceptible to soil disturbance. During the summer, the surface of these fields was kept free of any vegetation. This eliminated food for larvae and shelter for adults. The frequent soil disturbance also destroyed any pupae present in pupal cells.

Systematic rotations in Kansas with such crops as sweet sorghum, kafir, milo, and (under certain conditions) corn, reduced populations below economic levels. A system of rotation of wheat for 2 years,

sorghum for 1 year, and summer fallow for 1 year for western Kansas reduced false wireworm injury and increased yields (10, 19).

During summer months, large numbers of adults were found under Russian thistles and in clumps of volunteer grain and weeds in the fields as well as near the edges of fields (19, 26, 28, 29, 32).

Elimination of these sheltered situations by summer fallowing and by good weed control practices reduced both adults and larvae around individual fields. Summer fallowing not only controlled weeds but reduced roots and rotting vegetation, thus eliminating larval food. Frequent soil disturbances during this operation also destroyed eggs, young larvae, and pupae.

Summer fallowing was not effective in controlling *E. hispilabris* in Idaho because the adults moved from weedy hibernation sites to lay eggs in clean summer-fallowed fields. Elimination of weeds along field edges and in waste places resulted in good control, however (32).

Winter wheat seeded in August and September in Nebraska sustained very heavy damage by *E. opaca*. Since larval activity ended in October, recommendations were made to delay seeding until mid-October. There was a reduction in yield due to such late seeding; however, the loss to false wireworm larvae in wheat sown earlier exceeded this reduction in yield. Early seeded spring wheat was damaged by larvae that resumed feeding in March and April. If spring planting was delayed until May, the seeds escaped such larval damage. Late spring seeding, however, also resulted in a reduction in yield.

A farmer in Haakon County, South Dakota, having sustained about 60% damage to winter wheat in the fall, heavily seeded spring wheat in the damaged areas in April and had a satisfactory yield in spite of the continued presence of *E. opaca* larvae.

Chemical: Because recommendations for chemical control of insects change, the local county agricultural Extension agent should be consulted for current recommendations.

Parasitoids

A major parasitoid of false wireworm adults was *Perilitus eleodis* Viereck (18, 19, 20, 22, 26, 29). This parasitoid attacked all of the species of false wireworms found in South Dakota (18), though the incidence of parasitism rarely exceeded 10%.

A sarcophaged fly, *Sarcophaga eleodis* Aldrich, infected *E. suturalis, E. opaca, E. hispilabris, E. tricostata,* and *E. obsoleta* (1, 2, 26).

Three tachinid parasites that also attacked *Eleodes* sp. were *Eleodiphaga caffreyi* Walton, *E. pollimosa* Walton, and *Biomyia eleodivora* Walton. Nothing is known of their life cycles, however (33).

Predators

False wireworm adults appeared to be almost immune from predation because of defensive secretions which repelled both arthropod and vertebrate predators. Mammalian predators included mice and skunks (19, 29). Curiously, the grasshopper mouse (*Ohychomys* sp.) was able to avoid the defensive secretions of adults (12). Eggs, larvae, and pupae were vulnerable to a number of predators but since these stages occurred below the soil surface, they were afforded some measure of protection.

Of the arthropod predators, ground beetle larvae and adults seemed to be the most important. Several species of large carabids or ground beetles occurred in wheat fields in South Dakota. The larger and most voracious were *Calasoma calidum* F., *C. obsoletum* Say, *Pasimachus elongatus* Le Conte, and *Harpolas caliginosus* F. (29).

The only close predator-prey association identified involved *P. elongatus* and several species of false wireworms (8). Both adults and larvae fed on *Eleodes* larvae, and the spatial and temporal distribution of the predator corresponded very closely to that of *E. suturalis* and *E. opaca,* which indicated that it undoubtedly was a major predator of false wireworms.

The following birds were identified as predators of false wireworms by the former Bureau of Biological Survey, U. S. Department of Agriculture: crow, hairy woodpecker, sparrow hawk, road-runner, red-headed woodpecker, sage thrasher, mockingbird, magpie, purple grackle, meadowlark, Arkansas king bird, yellow-headed blackbird, loggerhead shrike, upland plover, mallard, baldpate, burrowing owl, northern shrike, and Brewer's blackbird (29). We observed lark buntings, western meadowlarks, horned larks, and dicksissels feeding in fields heavily infested with false wireworm larvae.

Diseases

Bacteria: Reddish brown spots that appeared in the cuticle of larvae of *E. suturalis* were described (18, 26, 29). These gradually enlarged, and usually resulted in death of the insect. This disease appeared to be contagious (26).

We observed similar spots on several larvae of *E. suturalis* in the laboratory. H. C. Schroeder, former graduate student, SDSU, isolated, cultured, and identified the disease organism as *Serratia marcescens* Bizio, an organism that has been implicated as a disease of several other insects. Early stages of the disease were often noted in field-collected larvae of *E. opaca.*

Fungi: Two fungi, *Sporonichum globuliferum* Speg. and *Metarrhizium anisopliae* (Metschnkoff) Sarokia, have been implicated as causing disease (20, 29).

Gregarines: A protozoan, identified as *Stylocephalus* sp., belonging to the subclass Gregarinidae, was found infesting the midgut of *E. suturalis* larvae in the laboratory and adults in the field. A species isolated from an unidentified *Eleodes* beetle was described by Ellis (13) as *S. giganteualles*. McColloch (19, 20) reported that this species also infected *E. tricostata* and *E. opaca*.

The life cycle of species of gregarines in the suborder Eugregarinina of which *Stylocephalus* is a member was described (24).

To determine how prevalent gregarine infections of field populations of false wireworms were throughout the summer in South Dakota, periodic examinations of the midgut of randomly selected *E. suturalis* and *E. opaca* beetles were made in 1967 and 1968.

The incidence of gregarine infection from field-collected *E. suturalis* is shown in Table 9. Examinations covered only about a 40-day period in 1967. Cysts were recorded from 6 of 8 adults that were infected on July 8. The trophozoites and sporonts were found in very large numbers and were of all sizes. Two gametocysts were also found in the feces of the adults. Beetles collected on other dates that year harbored no cysts and only low numbers of the free-living forms. In 1968, cysts were found in adults collected from the field on June 12 and 19 and on July 20. During the 50-day collection period, tropozoites and sporonts were found in large numbers on each collection date except July 3.

The incidence of infection of *E. opaca* adults is shown in Table 10. The period of examination in 1967 extended over 58 days. Trophozoites and sporonts were present in large numbers for each collection date, and cysts were observed in collections made on July 13, August 9, and September 8. The incidence and levels of infection in 1968 were low; however, the period of examination covered only 23 days. Cysts were not observed, and trophozoites and sporonts were found in very low numbers.

There did not appear to be a steady increase in incidence of infection of either species as the summer progressed. In grasshoppers, the incidence of infection of gregarines characteristically increased later in the summer and fall (24). However, the life cycle of grasshoppers was usually completed from egg to adult in one growing season.

In contrast, both *E. suturalis* and *E. opaca* overwintered as larvae. Because considerable larval feeding occurred in the fall, gregarines were probably ingested in the fall and carried through the winter within the alimentary tract. The newly emerged adults would be expected to harbor large numbers of these organisms that were ingested when they were larvae. Therefore, one would not expect a gradual increase in gregarine incidence in the adult stage through the growing season.

Most of the true gregarines inhabiting the alimentary tract of insects belong to the tribe Cephalina (24). These "gut" gregarines usually are not capable of causing harm to their hosts because tissue

Table 9. Incidence of gregarine infection from field-collected *E. suturalis* adults, 1967 and 1968.

Date	No. examined	% infection	Stages of development: Trophozoite	Cyst
1967				
July 1	12	25	Few (1-10)	None
July 8	13	54	Several (11-1000)	Few
July 14	11	36	Few	None
July 27	10	20	Few	None
August 9	3	66	Few	None
1968				
June 12	10	80	Several	Few
June 19	5	60	Several	Few
June 28	7	29	Several	None
July 3	6	33	Few	None
July 12	8	13	Several	None
July 20	7	57	Several	Few
July 26	5	20	Several	None
July 31	3	66	Several	None

damage caused by the attachment of trophozoites to the gut wall is compensated for by normal regeneration of the gut epithelium. Real damage is caused only by those species that infect and destroy cytoplasm of the host tissue (34).

Very little was known about Cephalina physiology and even less was known about the biological relationships between them and their hosts. Most workers considered them to be parasites that are well tolerated by their hosts. However, they do destroy epithelial cells and could have a weakening effect on the host that could decrease general activity and reproductive powers (24). In the field, where larvae are subjected to fluctuating temperature and moisture regimes, these gregarines may be a factor in growth or survival.

Table 10. Incidence of gregarine infections from field-collected *E. opaca* adults, 1967 and 1968.

Date	No. examined	% infection	Stages of development: Trophozoite	Stages of development: Cyst
1967				
July 13	15	60	Several (11-1000)	Few (1-10)
July 27	14	29	Several	None
August 9	15	93	Several	Few
August 25	11	64	Several	None
Sept. 8	8	88	Several	Few
1968				
June 19	6	0		
June 28	5	0		
July 3	8	63	Few	None
July 12	20	15	Few	None

Discussion and Conclusions

The laboratory and field life history data, when combined and interpreted, reveal which species of false wireworms are best adapted for damaging various crops. Their distribution in relation to field edge and topography gives insight into where localized damage would occur and what species would be involved. The distribution in relation to soil type allows one to predict which species might be important in various portions of the state.

Eleodes suturalis occurred in the active feeding stage at only one period that was critical for small grain production--during the fall when winter grains were sown. There appeared to be no danger to spring seeded grains. Crops such as grain sorghum and corn, which are seeded later in the spring, may be susceptible to the next generation of larvae arising from overwintered adults. This species could be important in most semi-arid portions of the state regardless of soil type.

Eleodes opaca larvae fed actively in both fall and spring and are potential threats to grain planted at either time. They occurred quite abundantly on both clay and sandy soil which comprised most of the winter wheat belt in South Dakota. This species probably is the most economically important false wireworm in the state because of its abundance and occurrence in all soils and its presence during critical periods.

Eleodes hispilabris occurred primarily on sandy soils and seemed to be a threat only to fall-seeded grains. High populations were never found in South Dakota during this study. Economic populations have been reported in Idaho and eastern Washington and only mentioned in passing by workers in the Great Plains states. The climatic conditions or the cropping sequences may have been detrimental to the life cycle of this species.

Eleodes tricostata was found to inhabit grasslands more abundantly than grain fields and occurred in more humid areas than other species. Larval feeding may be confined to the roots of grasses (19). To classify the potential of this species as a crop pest, a detailed study of its food habits should be conducted.

Eleodes extricata and *E. obsoleta* were found almost exclusively on sandy soils, and actively feeding larvae were found during both the fall and the spring, thus making these species threats to fall and spring-seeded grains. Although *E. obsoleta* was captured more frequently than *E. extricata*, it never occurred in large enough numbers to attract attention in the past or during this study. Thus, the conditions necessary to cause economic problems have not been identified for either species.

All stages of *E. muricatum* were present throughout most of the growing season, primarily on loam and sandy soils. The impact of the

population was not as severe because not all insects were in active feeding stages simultaneously. Most grain crops were susceptible to attack, and when populations are high enough, economic damage could occur during any part of the growing season.

False wireworms normally occur in low numbers in almost all wheat fields in western South Dakota. These populations are probably kept low by the practice of summer fallowing which removes food material and mechanically destroys certain stages of these insects. Although each species has one generation per year, the fecundity is high enough so that, under proper conditions, the population could increase dramatically in one or two generations. If wheat was grown for 2 or more consecutive years, serious build-ups of false wireworms could occur.

Several conditions would encourage farmers to grow wheat continuously. Higher yields could result from (1) drought resistant wheat varieties that would produce high yields with less rainfall than current varieties, and (2) occurrence of rain in early fall which would indicate to farmers that there was sufficient moisture to establish a stand and that the normal spring rains would carry the crop through to harvest. Seeding in stubble may also be a technique whereby a farmer might gamble that enough snow will be trapped so that moisture would be sufficient to create good yields. In addition, other factors influencing continuous wheat would include: (1) land prices and taxes high enough to convince farmers that they could not afford to let their land lie idle every other year; (2) the price of wheat increasing to the point that even a nominal yield would be profitable to harvest, and (3) relaxation of wheat acreage allotments. These factors would probably work in combination. The primary factor that farmers would use to determine whether it was practical to plant wheat continuously in a field would be available moisture. The other factors would either lower the minimum moisture threshold or would determine how willingly a grower would gamble on the outcome.

There is evidence that some farmers are now beginning to grow wheat continuously near Quinn and Elm Springs, South Dakota (P. A. Jones, formerly survey entomologist, SDSU, personal communication). Apparently, by applying liquid nitrogen and seeding in the stubble, yields were only reduced by 20%. Because the price of wheat had risen so sharply in 1973, even low yields of wheat became profitable to harvest. High prices will probably encourage still more farmers to grow wheat for consecutive years in the same fields.

When wheat is sown in the fall and sufficient moisture is available, germination occurs quite rapidly. Even though moderate populations of false wireworms might be present, most of the wheat would escape damage. If wheat was sown in the same field the following year, the insect population level would probably be higher because of higher larval survival, and even though sufficient moisture might be available for rapid germination, some damage would probably occur.

More importantly, the populations would increase each year that wheat was grown continuously until an economic threshold would be

reached. That threshold would depend both on the population level and on the amount of moisture available at seeding time. The amount of available moisture, if limited, would directly affect the speed of germination and would determine the length of time the plant would remain in the susceptible seed and young seedling stage.

The possibility of false wireworms becoming economically important after more than 40 years is not just idle speculation. B. H. Kantack and P. A. Jones (personal communication) reported that over 5,000 acres of wheat were destroyed by false wireworms in eastern Pennington County in 1973. During the previous 10 years, the only false wireworm damage in South Dakota was reported by the authors. Usually these widely scattered infestations were discovered in the course of conducting this study. It is interesting that the widespread damage by these insects is occurring in the same general area where wheat is being grown continuously. As this practice spreads, the insect problem will probably also increase. In the not too distant future, false wireworms may again be a limiting factor in the growth of dryland wheat on the Great Plains.

Acknowledgements

The authors would like to thank Betty Dupraz, Kathy Smith, Frank Post, Stewart Sutley, and Mark Lyle, Northern Grain Insects Research Laboratory, for technical assistance; G. R. Sutter, Northern Grain Insects Research Laboratory, for the photographs of adult false wireworms; and D. K. Morihara, graduate student, South Dakota State University, for the drawing of *Eleodes suturalis* (Say) that appears on the cover. We would also like to thank Dr. C. C. Burkhardt, University of Wyoming; Mr. A. G. Hagan, University of Nebraska, Scottsbluff Station; Dr. E. W. Hamilton, USDA-ARS, Gainesville, Fla.; Dr. B. H. Kantack, South Dakota State University; and Dr. J. W. Matteson, 3M Company, St. Paul, Minn., for critically reviewing the manuscript.

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