Project Number 79-F6

BIOLOGICAL CONTROL OF THE NAVEL ORANGEWORM WITH NEW NATURAL ENEMIES

Semi-annual Report
(Supplemental Information)

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E. F. Legner

Department of Entomology
University of California
Riverside, CA. 92521

This continuation of the semi-annual report is an enlargement of data made possible by results from navel orangeworm rearings over a period of 3 months. All Tables have been enlarged to include this information. A reassessment of the control plots at Nottelmann and Toy resulted in a lowering of the parasite impact figures (Tables 1 & 2), but did not otherwise change the conclusions submitted in November. Although the current data are still being critically analyzed, several previously unknown trends appear as follows, but which are subject to change as more data is gathered:

Diapause.--Mature field-collected larvae found to be in an apparent diapause after 3 months of incubation at 78° ± 3° F, ca. 50% RH and 14-h photoperiod ranged from 7-12% among the 4 orchards critically studied (Tables 3-6, 3-A, 6-A). We are performing an experiment to determine if this phenomenon is food-related, but already judging from the larvae's appearance and quiescence, an estivating-diapause appears quite probable. This offers some clue to the point-of-origin of the navel orangeworm in a region with several months of dry season. Such climates exist in South and Central America especially in western Argentina and Costa Rica. The larvae presently in diapause are being periodically examined for development, with some emergence having occurred after 4 months already noted.

Parasitism.--Natural parasitism by Pentalitomastix occurred in all 4 orchards averaging 4-20% of collected N.O.W. larvae (Tables 3-6). Goniozus was recovered from all plots in which this species was released, averaging 8-23% parasitism. Parasierola also reproduced in all orchards, but

averaged only 4-6% parasitism.

No parasitism was detected in collected peach twig borer larvae.

Table 9 gives estimates of respective parasite importance in regulating N.O.W. Two correlation analyses were performed. The first, on original data compared the relationship between N.O.W. density in a tree with parasitism, in an attempt to measure the response of parasites to fluctuations in N.O.W. densities. A parasite can be completely unresponsive to changes in its host's density, or it can take a constant percentage of the host thereby exerting some control effect. Correlation coefficients on original data for Pentalitomastix were significant at least to the 95% level in all orchards (Table 9), with values being highest (closest to 1.00) at Nottelmann and Toy. This suggests that Pentalitomastix is capable of killing a constant % of N.O.W. at fluctuating densities, but doesn't determine whether it can increase its rate of attack with rising host densities.

The second correlation analysis performed on log values and differences between initial N.O.W. density and final density after parasitism, was significant for Pentalitomastix in all orchards, suggesting that this parasite has a strong regulating capability. The significant coefficients show that Pentalitomastix parasitized more N.O.W. at higher densities than at lower densities (Table 9). Therefore, the possibility cannot be ruled out that Pentalitomastix acts as a vital mortality factor keeping the orangeworm down to its present levels in orchards where it has not been eliminated by insecticidal sprays. Conversely, it could be expected from these data that in the absence of Pentalitomastix, the N.O.W. would level out at a higher average level than is current (above 15% infestation).

Similarly, Goniozus showed highly significant correlation coefficients with both types of analyses (Table 9), so that its role as a potential regulatory factor seems probable, given its ability to survive in California. Parasierola appeared the least responsive to fluctuating N.O.W. densities up to the August sample, although some weak significant response was apparent in some orchards (Table 9).

Differences in response among the three parasites could reflect seasonal capabilities and does not negate a greater role of one or all species at other times of the year. Similarly, the apparent overall greater response of Goniozus as judged by higher correlation coefficients (pooled data in Table 9), could have resulted from the inundation of individuals around the sample trees. A more definite respective role of the three parasites will require a comparison of similar calculations from stick-tight samples and the 1980 harvest when natural establishment of the imported species may have resulted.

Table 1. Navel orangeworm, Amyelois transitella (Walker), damage to Nonpariel almond nuts sampled from parasite introduction and check (no parasites) orchards in August, 1979.

Parasite Species Released	PERCENT (& $s_{\bar{x}}$) DAMAGED NUTS [1/]					
	Nottelmann	Toy	Check	Tenneco West	Roberts Farms	Check
Chelonus sp.-- Ethiopia	6.33 (.50)	4.80 (.97)	9.85 (3.67)	1.13 (.52)	1.33 (.47)	5.00 (.55)
Chelonus sp.-- Australia	6.22 (1.13)	3.43 (.84)	"	2.11 (.66)	0.87 (.52)	"
Parasierola sp.-- Texas	5.56 (.50)	8.33 (1.48)	"	1.43 (.65)	2.56 (.63)	"
Bracon sp.-- Wasco	6.44 (1.14)	2.00 (.45)	"	1.14 (.51)	2.17 (.54)	"
Goniozus sp.-- Uruguay	8.00 (1.55)	1.67 (0.76)	"	1.89 (.48)	0.83 (.31)	"
Diadegma sp.-- Australia	4.50 (1.05)	7.43 (2.84)	"	3.67 (.88)	0.67 (.29)	"
AVG. TOTAL	6.18	4.61	9.85	1.90	1.41	5.00

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds).
Sample Dates: Nottelmann & Toy = 8/30/79; Tenneco & Roberts Farms = 8/21/79.

Table 2. Percent reduction of navel orangeworm, Amyelois transitella (Walker), damage to Nonpariel hull-split almonds sampled at harvest from three orchards in the Central Valley where parasites were introduced

Parasite Species Released	PERCENT REDUCTION (compared to control)[1/]		
	Nottelmann	Toy	Roberts Farms I
Chelonus sp.-- Ethiopia	35.7	51.3	73.4
Chelonus sp.-- Australia	36.9	65.2	82.6
Parasierola sp.-- Texas	43.6	15.4	48.8
Bracon sp.-- Wasco	34.6	79.7	56.6
Goniozus sp. Uruguay	18.8	83.1	83.4
Diadegma sp.-- Australia	54.3	24.6	86.6
AVG.	37.3	53.2	71.8

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds).

Sample Dates = Nottelmann & Toy: 8/30/79; Robert's Farms = 8/21/79
(Tenneco West too small to have a control)

Table 3. Navel orangeworm, Amyelois transitella (Walker), larvae and pupae extracted from cracked Nonpariel almond fruit sampled at Nottelmann's orchard on 8/30/79 and their development after 3 months incubation.

Parasite Species Released	NUMBER IN 100 ALMONDS[1]						
	Total Collected[2]		Diapause	Adults Emerged by 11/20/79 [3]			
	L	P	larvae?	N.O.W	Pent.	G.	P.
Chelonus sp.-- Ethiopia	4.89 (.68)	1.55 (.87)	0.44 (.24)	2.89 (.42)	2.22 (.78)	0 --	0 --
Chelonus sp.-- Australia	5.78 (1.90)	0.67 (.29)	0.56 (.29)	2.44 (.60)	1.78 (.55)	0 --	0 --
Parasierola sp.-- Texas	4.56 (.71)	0.78 (.32)	0.33 (.17)	2.00 (.29)	1.22 (.22)	0 --	0.22 (.15)
Bracon sp.-- Wasco, CA.	4.33 (1.00)	1.89 (.65)	0.56 (.24)	3.22 (.76)	1.33 (.47)	0 --	0 --
Goniozus sp.-- Uruguay	9.78 (2.04)	2.78 (.62)	1.11 (.48)	6.00 (1.07)	1.89 (.39)	1.44 (.44)	0 --
Diadegma sp.-- Australia	4.75 (1.57)	0.63 (.32)	0.87 (.40)	3.37 (1.37)	0.63 (.26)	0 --	0 --
Control (no parasites)	6.47 (2.42)	4.15 (2.01)	1.06 (.58)	6.59 (1.12)	1.64 (.52)	0 --	0 --

[1] Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); $s_{\bar{x}}$ in ().

[2] L = larvae, P = pupae.

[3] N.O.W. = navel orangeworm, Pent. = Pentalitomastix, G = Goniozus P = Parasierola.

Table 3-A. Percent of collected navel orangeworms emerged, in diapause after 3 months incubation and parasitized from collections at Nottelmann's orchard on 8/30/79.

Parasite Species Released	Percent Emerged				Percent	
	N.O.W.	Pentalitomastix	Goniozus	Parasierola	In Diapause	Dead 1/
Chelonus sp.-- Ethiopia	44.88	34.47	0	0	9.00	13.82
Chelonus sp.-- Australia	37.83	27.60	0	0	9.69	25.89
Parasierola sp.-- Texas	37.45	22.85	0	4.12	7.24	29.40
Bracon sp.-- Wasco, CA.	51.77	21.38	0	0	12.93	17.85
Goniozus sp.-- Uruguay	47.77	15.05	11.46	0	11.35	16.88
Diadegma sp.-- Australia	62.64	11.71	0	0	18.32	9.48
Control (no parasites)	62.05	15.44	0	0	16.38	12.52
AVG.	59.31	20.20	2.72	0.42	12.15	8.06

1/ dead from unknown causes (could include aborted parasitism).

Table 4. Navel orangeworm, Amyelois transitella (Walker), larvae and pupae extracted from cracked Nonpariel almond fruit sampled at Toy's orchard on 8/30/79 and their development after 3 months incubation.

Parasite Species Released	NUMBER IN 100 ALMONDS[1/]						
	Total Collected[2/]		Diapause	Adults Emerged by 11/20/79[3/]			
	L	P	larvae?	N.O.W.	Pent.	G	P.
Chelonus sp.-- Ethiopia	4.80 (1.11)	1.00 (.45)	0.20 (.20)	3.40 (.81)	0.80 (.49)	0 --	0 --
Chelonus sp.-- Australia	3.29 (.94)	0.29 (.18)	0.14 (.14)	2.29 (.86)	0.29 (.29)	0 --	0 --
Parasierola sp.-- Texas	5.00 (.77)	3.00 (.93)	0 --	3.50 (.43)	2.17 (.31)	0 --	0.50 (.34)
Bracon sp.-- Wasco, CA.	2.20 (.73)	0 --	0 --	1.00 (.45)	0.20 (.20)	0 --	0 --
Goniozus sp.-- Uruguay	1.50 (.56)	0.50 (.22)	0 --	1.17 (.54)	0.50 (.22)	0.17 (.17)	0 --
Diadegma sp.-- Australia	6.57 (2.48)	1.71 (.52)	0.71 (.29)	3.14 (.94)	1.57 (.37)	1.00 (.69)	0 --
Control(no parasites)	6.47 (2.42)	4.15 (2.01)	1.06 (.58)	6.59 (1.12)	1.64 (.52)	0 --	0 --

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); $s_{\bar{x}}$ in ().

2/ L = larvae, P = pupae.

3/ N.O.W. = navel orangeworm, Pent. = Pentalitomastix, G = Goniozus P = Parasierola.

Table 4-A. Percent of collected navel orangeworms emerged, in diapause after 3 months incubation and parasitized from collections at Toy's orchard on 8/30/79.

Parasite Species Released	Percent Emerged				Percent	
	N.O.W.	Pentalitomastix	Goniozus	Parasierola	In Diapause	Dead 1/
Chelonus sp.-- Ethiopia	58.62	13.79	0	0	4.17	24.14
Chelonus sp.-- Australia	63.97	8.10	0	0	4.26	24.02
Parasierola sp.-- Texas	43.75	27.13	0	6.25	0	22.88
Bracon sp.-- Wasco, CA.	45.45	9.09	0	0	0	45.45
Goniozus sp.-- Uruguay	58.50	25.00	8.50	0	0	8.00
Diadegma sp.-- Australia	37.92	18.96	12.08	0	10.81	22.46
Control (no parasites)	62.05	15.44	0	0	16.38	12.52
AVG.	52.10	17.71	2.89	1.24	7.07	20.85

1/ dead from unknown causes (could include aborted parasitism).

Table 5. Navel orangeworm, Amyelois transitella (Walker), larvae and pupae extracted from cracked Nonpariel almond fruit sampled at the Tenneco West, Chowchilla orchard on 8/21/79 and their development after 3 months incubation.

Parasite Species Released	NUMBER IN 100 ALMONDS[1]						
	Total Collected[2]		Diapause	Adults Emerged by 11/20/79[3]			
	L	P	larvae?	N.O.W.	Pent.	G.	P.
Chelonus sp.-- Ethiopia	0.78 (.36)	0.67 (.29)	0 --	0.56 (.29)	0 --	0 --	0 --
Chelonus sp.-- Australia	1.67 (.71)	1.00 (.64)	0 --	1.33 (.68)	0.22 (.15)	0 --	0.11 (.11)
Parasierola sp.-- Texas	1.00 (.44)	0.71 (.42)	0 --	1.29 (.52)	0 --	0 --	0 --
Bracon sp.-- Wasco, CA.	0.88 (.28)	0.11 (.11)	0 --	0.78 (.22)	0.22 (.15)	0 --	0 --
Goniozus sp.-- Uruguay	4.00 (1.01)	0.33 (.17)	0 --	2.67 (.76)	0.11 (.11)	1.00 (.33)	0 --
Diadegma sp.-- Australia	3.22 (.94)	1.11 (.51)	0.22 (.15)	2.89 (.87)	0.11 (.11)	0.22 (.22)	0 --
Control(no parasites)	[orchard too small for reliable control]						

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); $s_{\bar{x}}$ in ().

2/ L = larvae, P = pupae.

3/ N.O.W. = navel orangeworm, Pent. = Pentalitomastix, G = Goniozus P = Parasierola.

Table 5-A. Percent of collected navel orangeworms emerged, in diapause after 3 months incubation and parasitized from collections at Tenneco West, Chowchilla on 8/21/79.

Parasite Species Released	Percent Emerged				Percent	
	N.O.W.	Pentalitomastix	Goniozus	Parasierola	In Diapause	Dead 1/
Chelonus sp.-- Ethiopia	38.62	0	0	0	0	61.38
Chelonus sp.-- Australia	49.81	8.24	0	4.12	0	37.83
Parasierola sp.-- Texas	75.44	0	0	0	0	24.56
Bracon sp.-- Wasco, CA.	78.79	22.22	0	0	0	0
Goniozus sp.-- Uruguay	61.66	2.54	23.09	0	0	12.70
Diadegma sp.-- Australia	66.74	2.54	5.08	0	6.83	20.55
Control (no parasites)	[orchard too small for reliable control]					
AVG.	61.90	4.29	7.93	0.72	1.92	23.73

1/ dead from unknown causes (could include aborted parasitism).

Table 6. Navel orangeworm, Amyelois transitella (Walker), larvae and pupae extracted from cracked Nonpariel almond fruit sampled at Robert's Farms Site #1 (near office) on 8/21/79 and their development after 3 months incubation.

Parasite Species Released	NUMBER IN 100 ALMONDS [1]						
	Total Collected [2]		Diapause	Adults Emerged by 11/20/79 [3]			
	L	P	larvae?	N.O.W.	Pent.	G.	P.
Chelonus sp.-- Ethiopia	1.11 (.75)	0.78 (.43)	0 --	1.00 (.60)	0.44 (.24)	0 --	0 --
Chelonus sp.-- Australia	0.12 (.12)	0.38 (.38)	0 --	0.12 (.12)	0 --	0 --	0 --
Parasierola sp.-- Texas	1.67 (.60)	0.33 (.17)	0.44 (.34)	0.44 (.24)	0 --	0 --	0.11 (.11)
Bracon sp.-- Wasco, CA.	0.83 (.40)	0.50 (.22)	0 --	0.67 (.49)	0 --	0 --	0 --
Goniozus sp.-- Uruguay	0.83 (.40)	0.17 (.17)	0 --	0.67 (.33)	0 --	0.17 (.17)	0 --
Diadegma sp.-- Australia	0.33 (.17)	0 --	0 --	0.22 (.15)	0.11 (.11)	0 --	0 --
Control (no parasites)	2.60 (.51)	0.40 (.24)	0.40 (.24)	1.67 (.60)	0.22 (.22)	0 --	0 --

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); $s_{\bar{x}}$ in ().

2/ L = larvae, P = pupae.

3/ N.O.W. = navel orangeworm, Pent. = Pentalitomastix, G. = Goniozus P = Parasierola.

Table 6-A. Percent of collected navel orangeworms emerged, in diapause after 3 months incubation and parasitized from collections at Robert's Farms Site #1 (near office) on 8/21/79.

Parasite Species Released	Percent Emerged				Percent	
	N.O.W.	Pentalitomastix	Goniozus	Parasierola	In Diapause	Dead 1/
Chelonus sp.-- Ethiopia	52.91	23.28	0	0	0	23.81
Chelonus sp.-- Australia	24.00	0	0	0	0	76.00
Parasierola sp.-- Texas	22.00	0	0	5.50	26.35	50.50
Bracon sp.-- Wasco, CA.	50.38	0	0	0	0	49.62
Goniozus sp.-- Uruguay	67.00	0	17.00	0	0	16.00
Diadegma sp.-- Australia	66.67	33.33	0	0	0	0
Control (no parasites)	55.67	7.33	0	0	15.38	23.67
AVG.	47.66	7.66	1.69	1.09	11.21	33.53

1/ dead from unknown causes (could include aborted parasitism).

Table 7. Peach twig borer, Anarsia lineatella Zeller, larvae extracted from cracked Nonpariel almond fruit and subsequent adult emergence following 3 months incubation. Sampled from parasite introduction and control (no parasites) orchards in August, 1979.

Parasite Species Released	NUMBER IN 100 ALMONDS 1/ (& $s_{\bar{x}}$)											
	Nottelmann		Toy		Control		Tenneco West		Roberts Farms		Control	
	L	A	L	A	L	A	L	A	L	A	L	A
Chelonus sp.-- Ethiopia	0.11 (.11)	0.11 (.11)	0 --	-- --	0.33 (.33)	0.14 (.14)	1.67 (.71)	0 --	0.89 (.31	2/	0.60 (.40)	2/
Chelonus sp.-- Australia	0.44 (.18)	0.33 (.17)	0 --	-- --	"	"	1.67 (.41)	0.44 (.17)	2.87 (.85)	"		"
Parasierola sp. Texas	0 --	-- --	0.33 (.21)	0.33 (.21)	"	"	1.00 (.38)	0 --,	4.44 (1.03)	"		"
Bracon sp.-- Wasco, CA.	0.22 (.15)	0 --	0.20 (.20)	0.20 (.20)	"	"	1.44 (.47)	0 --	1.50 (.56)	"		"
Goniozus sp.-- Uruguay	0.22 (.15)	0 --	0 --	-- --	"	"	1.67 (.67)	0.44 (.18)	0.17 (.17)	"		"
Diadegma sp.-- Australia	0.11 (.11)	0 --	0 --	-- --	"	"	1.11 (.59)	0.11 (.11)	0.44 (.29)	"		"
AVG.	0.16	0.07	0.09	0.09	0.33	0.14	1.43	0.17	1.72	"	0.60	"

1/ Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); sample dates = Nottelmann & Toy (8/30/79) Tenneco & Roberts (8/21/79). L = larvae, A = emerged adults.

2/ larvae not incubated.

Table 8. Dried and total reject Nonpariel almonds sampled from parasite introduction and check (no parasites) orchards in August, 1979.

Parasite Species Released	PERCENT (& $s_{\bar{x}}$) DRIED NUTS AND TOTAL REJECTS [1/]											
	Nottelmann		Toy		Check		Tenneco West		Roberts Hqts.		Check	
	dried nuts	total reject	dried nuts	total reject	dried nuts	total reject	dried nuts	total reject	dried nuts	total reject	dried nuts	total reject
Chelonus sp.-- Ethiopia	1.33 (.60)	7.66	1.60 (.60)	6.40	3.67 (2.73)	16.54	0 --	1.13	0 --	1.33	1.00 0	6.00
Chelonus sp.-- Australia	0.44 (.34)	6.66	0 --	3.43	"	"	0 --	2.11	0 --	0.87	"	"
Parasierola sp.-- Texas	0 --	5.56	2.50 (.72)	10.83	"	"	0 --	1.43	0 --	2.56	"	"
Bracon sp.-- Wasco	0.11 (.11)	6.55	0.80 (.37)	2.80	"	"	0 --	1.14	0 --	2.17	"	"
Goniozus sp.-- Uruguay	0.78 (.40)	8.78	0 --	1.67	"	"	0 --	1.89	0 --	0.83	"	"
Diadegma sp. Australia	1.13 (.40)	5.63	0 --	7.43	"	"	0 --	3.67	0 --	0.67	"	"
AVG. TOTAL	0.63	6.81	0.82	5.43	3.67	16.54	0	1.90	0	1.41	1.00	6.00

[1/] Avg. of 9 trees, 100 husk-split almonds per tree (900 almonds); sample dates: Nottelmann & Toy = 8/30/79, Tenneco & Roberts Farms = 8/21/79.

Table 9. Estimates of parasite impact on navel orangeworm in 4 orchards through a measure of the relationship between host density and parasitism.

Orchard	Species	Analysis Type 1/	Density per 100 almonds	Correlation with N.O.W. Corr. Coeff. (r)	t	Signif. level	df
Nottelmann	N.O.W.	--	7.09	--	--	--	--
	Pentalitomastix	Orig.	1.53	0.6344	5.74	99	49
		log	--	0.6191	5.52	99	"
	Goniozus	Orig.	1.44	0.7543	2.81	95	6
		log	--	0.5000	1.41	80	"
	Parasierola	Orig.	0.22	0.2887	0.80	ns	7
		log	--	0.3397	0.96	ns	"
	Total Parasites	Orig.	--	0.7881	9.05	99	50
		log	--	0.5391	4.53	99	"
Toy	N.O.W.	--	5.08	--	--	--	--
	Pentalitomastix	Orig.	0.94	0.5912	4.08	99	31
		log	--	0.6875	5.27	99	"
	Goniozus	Orig.	0.17	0.5774	1.00	ns	2
		log	--	0.5774	1.00	ns	"
	Parasierola	Orig.	0.50	0.2835	0.59	ns	4
		log	--	0.3373	0.72	ns	"
	Total Parasites	Orig.	--	0.8034	7.51	99	31
		log	--	0.6099	4.29	99	"
Tenneco West	N.O.W.	--	2.62	--	--	--	--
	Pentalitomastix	Orig.	0.12	0.3205	2.06	95	37
		log	--	0.4022	2.67	98	"
	Goniozus	Orig.	1.00	0.4526	1.24	70	6
		log	--	0.8492	3.94	99	"
	Parasierola	Orig.	0	--	--	--	--
		log	--	--	--	--	--
	Total Parasites	Orig.	--				
		log	--				
Roberts' Farms-I	N.O.W.	--	1.19	--	--	--	--
	Pentalitomastix	Orig.	0.11	0.4161	2.19	95	23
		log	--	0.5359	3.04	99	"
	Goniozus	Orig.	0.17	0.5774	1.00	ns	2
		log	--	0.5774	1.00	ns	"
	Parasierola	Orig.	0.11	0.1203	0.36	ns	9
		log	--	0.0324	0.09	ns	"
	Total Parasites	Orig.	--	0.3631	1.87	90	23
		log	--	0.5323	3.02	99	"
Pooled (4 orchards)	N.O.W.	--	4.01	--	--	--	--
	Pentalitomastix	Orig.	0.68	0.6731	10.99	99	146
		log	--	0.6795	11.19	99	"
	Goniozus	Orig.	0.80	0.6856	4.42	99	22
		log	--	0.7298	5.01	99	"
	Parasierola	Orig.	0.19	0.3347	1.74	90	24
		log	--	0.3495	1.83	90	"
	Total Parasites	Orig.	--	0.7886	15.55	99	147
		log	--	0.6613	10.69	99	"

1/ original = No. N.O.W. vs parasitized N.O.W. (per 100 almonds);
log = $\log_n$ No. N.O.W. vs ($\log_n$ No. N.O.W. − $\log_n$ No. parasitized N.O.W.)