A Long-Term Survey of Parasitoid Species Composition and Parasitism of *Trichoplusia ni* (Lepidoptera: Noctuidae), *Plutella xylostella* (Lepidoptera: Plutellidae), and *Pieris rapae* (Lepidoptera: Pieridae) in Minnesota Cabbage[1]

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Abstract Field studies were conducted near Rosemount, MN, during the years 1991-1994, 1996-1997, and 1999-2003, to assess the diversity of and parasitism by larval and pupal parasitoids of cabbage looper, *Trichoplusia ni* (Hübner), imported cabbageworm, *Pieris rapae* (L.), and diamondback moth, *Plutella xylostella* (L.). Species composition, parasitism rate, and species abundance (Hill's *N*1) were determined for each pest species. *Voria ruralis* (Fallen), *Copidosoma floridanum* (Ashmead), and *Compsilura concinnata* (Meigen) were the dominant parasitoids of *T. ni; Phryxe pecosensis* (Townsend), *Cotesia glomerata* (L.), and *Pteromalus puparum* (L.) are the dominant parasitoids of *P. rapae;* and *Diadegma insulare* (Cresson) is the dominant parasitoid of *P. xylostella.* In addition, the first records of the introduced parasitoid, *C. concinnata,* parasitizing *T. ni* and *P. rapae,* and *Cotesia rubecula* (Marshall) parasitizing *P. rapae* are documented for Minnesota.

Key Words cabbage, parasitoid, biological control, *Compsilura concinnata, Cotesia glomerata, Diadegma insulare*

Cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), imported cabbageworm, *Pieris rapae* (L.) (Lepidoptera: Pieridae), and diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), are the most economically damaging pests of cabbage, *Brassica oleracea* var. *capitata* L., in Minnesota (Noetzel et al. 1985, Subramanyam et al. 1996). Management of these pests is primarily achieved through the use of action thresholds and insecticides (e.g., Mahr et al. 1993, Hines and Hutchison 2001, Hutchison et al. 2004). However, there are numerous natural enemies that often reduce insect pest pressure in the midwestern U.S. (e.g., Mahr et al. 1993). Documentation of the natural enemies associated with cabbage pests is a necessary step in developing an integrated pest management (IPM) system. The cabbage pest and natural enemy complex in Minnesota has been documented in the past (e.g., Weires and Chiang 1973). However, no recent information on larval and

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pupal parasitoid species in Minnesota has been published. During the 1990's, we observed a shift in the lepidopteran pest complex in cabbage, with *T. ni* becoming the dominant pest (Hines 1998, Hutchison et al. 1993, Hutchison and Burkness 1999). By contrast, during the late 1960's, Weires and Chiang (1973) found that *P. rapae* was the dominant lepidopteran pest. As this shift in pest species occurred, it is possible that the parasitoid complex also changed.

Weires and Chiang (1973) conducted a comprehensive study detailing arthropod species composition in Minnesota cabbage during 1968-1970. They documented a diverse food web, including the dominant insect herbivores, predators, and parasitoids associated with cabbage, for a total of 160 species. In this paper we compare the larval and pupal parasitoid species found by Weires and Chiang (1973) to parasitoids recovered from lepidopteran pests since 1991 in Minnesota cabbage.

Materials and Methods

During the years 1968-1970, 1991-1994, 1996-1997, and 1999-2003, larvae, prepupae, and pupae of *P. xylostella, P. rapae,* and *T. ni* were surveyed for parasitism in cabbage fields near Rosemount, MN (Dakota Co.), at the Rosemount Agricultural Experiment Station, University of Minnesota. Surveys from 1968-1970 are described in Weires and Chiang (1973). For the years 1991-2003, insects were hand-collected and placed individually on cabbage leaves in 29-ml plastic cups (Bio-Serv, Frenchtown, NJ). Individuals were placed in coolers, transferred to the laboratory within 0.5 to 2h, and reared until adulthood or parasitoid emergence. Below, we describe cabbage varieties used; plot sizes and sampling protocols are provided for specific time frames and studies.

1968-1970. Cabbage (cv. 'Chieftan Savoy', 'Red Hollander', 'Wisconsin All Seasons', and 'Wisconsin Golden Acre') was planted in an area measuring 0.1-0.2 ha. Between 36 and 132 cabbage plants were sampled weekly for the presence of *T. ni, P. rapae,* and *P. xylostella* larvae and pupae. In addition, percent parasitism was determined for each pest species. Additional information for the methods used for the years 1968-1970 is described in Weires and Chiang (1973).

1991-1992. Cabbage (cv. 'Super Elite') was transplanted on 14 June 1991 and 10 June 1992 into plots with two rows, each row measuring 12.2 m in length. No insecticides were applied to cabbage plots during each year. In 1991, totals of 42 *T. ni* and 85 *P. rapae* larvae and pupae were collected, whereas in 1992, 379 *T. ni* and 80 *P. rapae* larvae and pupae were collected. No *P. xylostella* larvae or pupae were collected in either year. In addition to collecting native parasitoids, we released *Cotesia* (=*Apanteles*) *rubecula* Marshall (Hymenoptera: Braconidae) at Rosemount, in a nearby collard plot not treated with insecticides, on 26 August 1992. Totals of 12 and 59 *C. rubecula* adults were released, originating from Chinese and Yugoslovian strains, respectively (W.D. Hutchison, unpub. data). Additional information for the methods used for 1991 and 1992 are described in Hutchnson et al. (1993).

1993-1994. Cabbage (cv. 'Super Elite') was transplanted on 22 June 1993 and 14 June 1994 into plots of four rows, each measuring 7.6 m in length. No insecticides were applied to plots. In 1993, 72 *T. ni* and 72 *P. rapae* larvae and pupae were collected on 19 August. In 1994, 99 *T. ni* and 71 *P. rapae* larvae and pupae were collected on 17 August. No *P. xylostella* larvae or pupae were collected.

1996-1997: Cabbage (cv. 'Gourmet') was transplanted on 27 June 1996 and 17 June 1997. Plots were four rows, each measuring 7.6 m, with 102 cm row spacing.

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Insecticides were not applied to cabbage plots. In 1996, 661 *P. rapae,* 373 *T. ni,* and 199 *P. xylostella* larvae and pupae were collected on 29 August and 6 September. In 1997, 562 *T. ni,* 351 *P. rapae,* and 119 *P. xylostella* were collected on 25 August, 29 August, and 5 September. Additional information for the methods used for 1996-1997 are described in Hines (1998).

1999: Cabbage (cv. 'Morris') was transplanted on 30 June in commercial fields in Rosemount, MN. Insects were collected from untreated plots consisting of three rows, 21.3 m in length, with 102 cm row spacing. Collections of 107 *T. ni,* 29 *P. rapae,* and 55 *P. xylostella* larvae and pupae were made on 10 August.

2000-2003: Cabbage (cv. 'Gourmet) was transplanted on 22 June 2000, 8 June 2001, 6 June 2002, and 5 June 2003 in Rosemount, MN. In 2000 and 2001, eight and 16 plots, respectively, of 10 rows measuring 20 m in length with 100 cm row spacing, were planted. In both 2002 and 2003 plots were 12 rows measuring 20 m, with 100 cm row spacing. All plots were planted within soybean fields as part of a larger study of parasitoid dispersal; no insecticides were applied. Between 4 July and 27 September 2000, 348 *T. ni,* 1064 *P. rapae* and 495 *P. xylostella* larvae and pupae were collected. Between 26 June to 30 August 2001, 1134 *T. ni,* 1676 *P. rapae* and 1036 *P. xylostella* were collected. We collected 76 *T. ni,* 634 *P. rapae* and 519 *P. xylostella* between 27 June and 10 September 2002, and 157 *T. ni,* 982 *P. rapae* and 1624 *P. xylostella* between 26 June and 29 August 2003.

2003 (commercial field). Cabbage (cv. 'Bronco') was direct seeded on 5 June. Plots consisted of 20 rows, measuring 7.62 m in length and 102 cm row spacing. Individual plots were a part of a 20 ha commercial cabbage field. No insecticides were applied to cabbage plots. On 5 and 22 August, we collected 118 *T. ni* and 89 *P. xylostella* larvae and pupae. Due to low densities of *P. rapae,* none were collected.

Data analysis. For each pest species, we determined the species composition (%) in a given year, and the overall parasitism rate (%). Average parasitism of larval and pupal stages were combined. We also determined the parasitism rate across all years, using a weighted average. Individuals dying from pathogens or unknown causes were not included in the calculations. In addition, we used Shannon's index (eq. 1), where H' is the average uncertainty in predicting the species to which a randomly chosen individual belongs, in a community made up of s* species with known proportional abundances (p_i), to determine Hill's $N1$ (eq. 2), which measures the number of abundant species for a given year (Ludwig and Reynolds 1988, Wold et al. 2001), and analyzed those values with Fisher's protected LSD.

$$H' = -\sum_{i=1}^{s^*} (p_i \ln p_i) \quad (1)$$

$$N1 = e^{H'} \quad (2)$$

Voucher specimens of parasitoids collected in 1991-1994 and 1996-1997 were placed in the University of Minnesota Insect Museum, Department of Entomology.

Results and Discussion

***T. ni* parasitism.** During 1968-1970, Weires and Chiang (1973) observed a parasitism rate of 2.0% at Rosemount, MN (Table 1). Although the authors only quantified parasitism levels for one species, *Voria ruralis* that parasitized *T. ni* (Table 1), they

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Table 1. Overall parasitism rate of *T. ni*, *P. rapae*, and *P. xylostella*, and the relative contributors of parasitoids reared from each pest species, 1968-1970; Rosemount, MN (Weires and Chiang 1973)

	Trichoplusia ni		*Pieris rapae*			*Plutella xylostella**	
Year	Overall percent parasitism	*Voria ruralis*	Overall percent parasitism	*Pteromalus puparum*	*Cotesia glomerata*	Overall percent parasitism	*Diadegma insulare*** *Diadromus subtilicornis****
1968	4.0	4.0	31.0	31.0	0.0	34.0	34.0
1969	0.0	0.0	21.4	4.4	17.0	8.0	8.0
1970	2.0	2.0	30.0	24.0	6.0	5.0	5.0
$\bar{x}$	2.0	2.0	27.5	19.8	7.7	15.7	15.7

* Parasitoid data were not able to be split out by individual species.
** *Diadegma plutellae* (Ashmead) as reported in Weires and Chiang 1973.
*** *Diadromus plutellae* (Ashmead) as reported in Weires and Chiang 1973.

also acknowledged finding *Stenichneumon culpator cincticornis* (Cresson) (Hymenoptera: Ichneumonidae). By contrast, during the years 1991-2003, we found numerous parasitoid species attacking *T. ni* (Table 2). For all years, on average, the dominant species that emerged from our samples included *Voria ruralis* (Fallen) (Diptera: Tachinidae), *Copidosoma floridanum* (Ashmead) (Hymenoptera: Encyrtidae), and *Compsilura concinnata* (Meigen) (Diptera: Tachinidae). Although *V. ruralis* was the predominant parasitoid in the majority of our samples, parasitism by *V. ruralis* dramatically declined in 1996, and was absent in 1997 and 1999. These events could be due to many different factors, including weather and host density. Moreover, *V. ruralis* is a generalist parasitoid (Elsey and Rabb 1970); therefore, it is possible that *V. ruralis* existed on alternate hosts during these years.

Campoletis spp. and *Gambrus canadensis* (Provancher) (Hymenoptera: Ichneumonidae) were observed only during 2000 and 2001, respectively, whereas *Gambrus ultimus* (Cresson) and *Vulgichneumon brevicinctor* (Say) (Hymenoptera: Ichneumonidae) were both observed in 1997 and 2001. *Iseropus sterocorator orgyiae* Ashmead (Hymenoptera: Ichneumonidae) was observed during 1992, 1997, and 2001. *Itoplectis conquisitor* (Say) (Hymenoptera: Ichneumonidae) was recovered only during the years 1992 and 1997, whereas *S. c. cincticornis* was found in 1992, 1997, and 1999 through 2003. *Compsilura concinnata* was first observed in 1994, and it rapidly became a major parasitoid in subsequent years. The ectoparasitoid *Euplectrus plathypenae* (Howard) (Hymenoptera: Eulophidae) was observed in 2001 and 2003 and parasitized 15.1% and 0.5% of *T. ni*, respectively. The overall percentage of parasitized *T. ni* recovered from cabbage varied between 2.8 and 75% over the years sampled (Table 2). The weighted average parasitism rate across all years was 39.8% (Table 2). A similar study in New York State, from 1979-1981, and 1991-1994, found a parasitism rate of 2.5% (Shelton et al. 2002). In 2000 and 2001, *V. ruralis* was attacked by various hyperparasitoids, including *Conura side* (Walker) and *Brachymeria ovata* (Say) (Hymenoptera: Chalcididae) (data not shown); the hyperparasitism rate in 2000 and 2001 was relatively low (2.0% and 3.6%, respectively).

***P. rapae* parasitism.** Average percent parasitism for all parasitoids combined, for

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Table 2. Overall parasitism and relative contributors of each parasitoid species to the overall parasitism of the cabbage looper, *T.ni*, in cabbage, selected years, 1991-2003, Rosemount, MN

Year	Overall percent parasitism (*n*)*	*Voria ruralis*	*Euplectrus plathypenae*	*Copidosoma floridanum*	*Stenichneumon c. cincticornis*	*Compsilura concinnata*	*Iseropus s. orgyiae*	*Vulgichneumon brevicinctor*	*Campoletis spp.*	*Gambrus ultimus*	*Itoplectis conquisitor*	*Gambrus canadensis*
1991**	28.0 (42)	21.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1992**	18.1 (379)	13.2	0.0	0.0	3.2	0.0	1.3	0.0	0.0	0.0	0.3	0.0
1993	2.8 (72)	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	75.0 (99)	69.0	0.0	5.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
1996***	8.9 (123)	0.8	0.0	4.9	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0
1997***	31.6 (136)	0.0	0.0	2.9	9.6	11.0	0.7	4.4	0.0	1.5	1.5	0.0
1999	26.7 (127)	0.0	0.0	20.5	4.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0
2000†	26.4 (348)	14.7	0.0	9.2	1.4	0.9	0.0	0.0	0.3	0.0	0.0	0.0
2001†	65.2 (1134)	46.3	15.1	2.1	0.4	0.2	0.2	0.1	0.6	0.1	0.0	0.1
2002†	40.5 (79)	36.7	0.0	1.3	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003†	3.8 (157)	0.0	0.5	1.9	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0
2003	6.0 (118)	3.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Weighted $\bar{x}$	39.8	26.3	6.1	3.7	1.5	1.1	0.3	0.3	0.3	0.1	0.1	<0.1
Insect stage attacked‡		L	L	E	P	L	P	P	L	P	P	P
Insect stage collected§		L, EP	L	L, P	P	L, P	P	P	L	P	P	P

* Total number of *T. ni* collected.
** Hutchison et al. (1993).
*** Hines (1998).
† Data collected from plots surrounded by soybeans.
‡ Indicates the specific stage of the host that parasitoids were observed parasitizing their host (L = larva, P = pupa, E = egg, EP = early pupa).
§ Indicates the specific stage of the host that was collected.

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the years 1968-1970, was similar to that of 1991-2003 (27.5%, Table 1, and 33.5% Table 3, respectively). These results are also compatible with Shelton et al. (2002), who found an overall *P. rapae* parasitism rate of 20.0%. Since 1991, *Phryxe pecosensis* (Townsend) (Diptera: Tachinidae), *Cotesia glomerata* (L.) (Hymenoptera: Braconidae), and *Pteromalus puparum* (L.) (Hymenoptera: Eulophidae) were the dominant species recovered from *P. rapae* (Table 3). As with parasitoids of *T. ni, C. concinnata* was first observed in 1994. During 1997, *C. concinnata* became the dominant parasitoid, parasitizing over 28.3% of *P. rapae* (Table 3). In New York, however, *C. concinnata* parasitized only 0.2% of *P. rapae* (Shelton et al. 2002). Although *C. rubecula* was released in 1992, it was not recovered until the years 2000, 2001 and 2003, at <4%. *Cotesia rubecula* is an introduced parasitoid, and via multiple releases, has become well established in British Columbia (Corrigan 1982), Washington (Biever 1992), and Michigan (Pyle 1995). *Itoplectis conquisitor* and *G. ultimus,* both of which are also parasitoids of *T. ni,* were only observed during 1996 and 2001, respectively. We also found *P. rapae* pupae that were parasitized multiple times by both *P. puparum* and *G. ultimus,* or *P. puparum* and *G. canadensis.* The highest parasitism rate occurred in 1997, at 50.3% (Table 3). In 2000 we observed 0.1% hyperparasitism of *C. glomerata,* and in 2001, 9.0% hyperparasitism of *C. rubecula* by various species, including *C. side* (data not shown).

***P. xylostella* parasitism.** Across all years, the dominant parasitoid found in our samples was *Diadegma insulare* (Cresson) (Hymenoptera: Ichneumonidae) (Table 4). The overall parasitism rate was relatively high at 76.3% (Table 4). Weires and Chiang (1973) reported a much lower overall parasitism rate of 15.7% (Table 1). Shelton et al. (2002) also reported *D. insulare* as the dominant parasitoid in New York and observed a similarly high parasitism rate of 56.0%. In our study, parasitism of *P. xylostella* was highest in 1997 at 83.8%. We observed *Oomyzus incertus* (Ratzeburg) (Hymenoptera: Eulophidae) and *Microplitis plutellae* (Muesebeck) (Hymenoptera: Braconidae) during the years of 1996, and 2000-2003, with a relatively low average parasitism rate of 1.6% and 0.5%, respectively. Similarly, *Diadromus* sp. (Hymenoptera: Ichneumonidae) was recovered from collections taken during the years of 1996, 1997, and 2001-2003, with an average parasitism rate of 0.4%. During the years of 2000-2003, *D. insulare* was attacked by various hyperparasitoids, including *C. side,* which attacks the pupal stage (J. Lee, unpub. data), and *Bathythrix triangularis* (Cresson) (Hymenoptera: Ichneumonidae). In 2001, the level of hyperparasitism of *D. insulare* was low (<4%); however, during 2003 the level of hyperparasitism was much higher (>28%, data not shown).

Species diversity and abundance. The number of abundant parasitoid species as defined by Hill's *N*1, recovered from *T. ni,* in each year ranged between 1.0 and 4.2 (Table 5). The greatest number of abundant species was found in 1996 and 1997 with 4.2 and 3.4 species, respectively (Table 5).

The number of abundant parasitoid species recovered from *P. rapae,* for data collected between 1991 and 2003, was between 1.0 and 3.8, with the greatest number of abundant species found during 2000 (Table 5). In contrast, Weires and Chiang (1973) only reported two parasitoid species for *P. rapae,* and the values for abundant species for *P. rapae* did not exceed 1.7 (Table 5).

Hill's *N*1 for parasitoid species recovered from *P. xylostella* did not exceed 1.3 in any year (Table 5). Weires and Chiang (1973) did not differentiate between species parasitized by *D. insulare* or *D. subtilicornis;* therefore we could not determine Hill's *N*1.

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Table 3. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the imported cabbageworm, *P. rapae,* in cabbage, selected years, 1991-2003, Rosemount, MN

Year	Overall percent parasitism, (*n*)*	Species of parasitoids recovered from *Pieris rapae* (%)								
		Pteromalus puparum	*Phryxe pecosensis*	Unidentified**	*Cotesia glomerata*	*Cotesia rubecula*	*Compsilura concinnata*	*Gambrus ultimus*	*Gambrus canadensis*	*Itoplectis conquisitor*
1991***	32.0 (85)	9.4	20.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
1992***	21.2 (80)	10.0	10.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
1993	38.0 (72)	17.0	0.0	17.0	4.0	0.0	0.0	0.0	0.0	0.0
1994†	40.0 (71)	0.0	25.0	0.0	11.0	0.0	4.0	0.0	0.0	0.0
1996†	17.4 (195)	5.6	9.2	0.0	0.5	0.0	1.5	0.0	0.0	0.5
1997	50.3 (127)	7.1	3.1	0.0	11.8	0.0	28.3	0.0	0.0	0.0
1999	12.2 (98)	11.2	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
2000‡	38.5 (1064)	4.4	18.2	6.5	8.5	0.7	0.3	0.0	0.0	0.0
2001‡	47.1 (1676)	28.1	4.8	9.7	0.0	3.5	0.2	0.4	0.2	0.1
2002‡	6.8 (634)	4.6	0.6	0.6	0.0	0.0	0.9	0.0	0.0	0.0
2003‡	25.7 (982)	16.9	0.6	0.1	0.8	3.9	3.1	0.1	0.0	0.2
Weighted $\bar{x}$	33.5	15.2	6.9	4.9	2.5	2.1	1.7	0.05	0.02	0.7
Insect stage attacked§		P	L		L	L	L	P	P	P
Insect stage collected£		P	L, P		L	L	L, P	P	P	P

* Total number of *T. rapae* collected.
** Includes parasitoids that were not identified to species.
*** Hutchison et al. (1993).
† Hines (1998).
‡ Data collected from plots surrounded by soybeans.
§ Indicates the specific stage of the host that parasitoids were observed parasitizing their host (L = larva, P = pupa, E = egg, EP = early pupa).
£ Indicates the specific stage of the host that was collected.

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Table 4. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the diamondback mother, *P. xylostella,* in cabbage, selected years, 1994-2003, Rosemount, MN

		Species of parasitoids recovered from *Plutella xylostella* (%)			
Year	Overall percent parasitism, (*n*)*	*Diadegma insulare*	*Oomyzus incertus***	*Microplitis plutellae*	*Diadromus* sp.
1994	72.5 (40)	72.5	0.0	0.0	0.0
1996	78.6 (182)***	75.3	2.2	0.5	0.5
1997	83.8 (99)***	81.8	0.0	0.0	2.0
1999	68.0 (25)	68.0	0.0	0.0	0.0
2000†	74.5 (495)	72.3	1.4	0.8	0.0
2001†	74.2 (1036)	70.8	2.8	0.1	0.7
2002†	65.9 (519)	61.7	3.3	0.2	0.8
2003†	81.5 (1624)	79.8	0.6	0.9	0.2
2003	66.3 (89)	65.2	1.1	0.0	0.0
Weighted $\bar{x}$	76.3	73.7	1.6	0.5	0.4
Insect stage attacked‡		L	L	L	P
Insect stage collected§		L, EP	L, P	L	P

* Total number of *P. xylostella* collected.
** = name changed to *Tetrastichus incertus* (Ratzeburg) after 1996.
*** Hines (1998).
† Data collected from plots surrounded by soybeans.
‡ Indicates the specific stage of the host that parasitoids were observed parasitizing their host (L = larva, P = pupa, E = egg, EP = early pupa).
§ Indicates the specific stage of the host that was collected.

Our collections over 11 summers, along with the results of Weires and Chiang (1973), allowed us to document shifts in the major larval and pupal parasitoid species attacking cabbage Lepidoptera in southern Minnesota. The most recent dominant parasitoids include: *V. ruralis, C. floridanum,* and *C. concinnata* on *T. ni,* and *P. pecosensis, C. glomerata,* and *P. puparum* on *P. rapae.* Unlike the results for *T. ni* and *P. rapae, D. insulare* continues to be the most abundant species parasitizing *P. xylostella,* and parasitism of this pest averaged 73.7%. In the 1950's, Harcourt (1960) also found *D. insulare* to be the most effective parasitoid of *P. xylostella* in southern Ontario. Our results are also similar to those of Shelton et al. (2002) in New York, with the exception of parasitoids recovered from *T. ni.* Although we found *V. ruralis* to be a dominant parasitoid of *T. ni* Shelton et al. (2002) found *C. concinnata* to be the dominant parasitoid, for collections made from 1979-1981 and 1991-1994.

Compsilura concinnata was first found to parasitize *T. ni* in Minnesota in 1996. This species reached elevated parasitism levels in subsequent years. In 1997 *C. concinnata* also became the dominant parasitoid recovered from *P. rapae,* while the inci-

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Table 5. Diversity of parasitoid species recovered from parasitized *T. ni, P. xylostella,* and *P. rapae,* selected years, 1994-2003, Rosemount, MN

Year	*Trichoplusia ni* Sum of species*	*Trichoplusia ni* Hill's *N*1**	*Pieris rapae* Sum of species	*Pieris rapae* Hill's *N*1	*Plutella xylostella* Sum of species	*Plutella xylostella* Hill's *N*1
1968	1.0	1.0	1.0	1.0	nd***	nd***
1969	nd†	nd†	2.0	1.7	nd***	nd***
1970	1.0	1.0	2.0	1.7	nd***	nd***
1991	1.0	1.8	3.0	2.3	nd‡	nd‡
1992	4.0	2.2	3.0	2.7	nd‡	nd‡
1993	1.0	1.0	3.0	2.6	nd‡	nd‡
1994	3.0	1.2	3.0	2.4	1.0	1.0
1996	5.0	4.2	5.0	2.5	4.0	1.2
1997	7.0	3.4	4.0	2.6	1.0	1.0
1999§	1.0	1.0	0.0	0.0	1.0	1.0
2000§	5.0	2.8	6.0	3.8	3.0	1.2
2001§	9.0	1.5	8.0	3.2	4.0	1.2
2002§	3.0	1.5	4.0	2.7	4.0	1.3
2003§	3.0	2.6	8.0	2.9	4.0	1.1
2003	2.0	1.9	—	—	3.0	1.3

* Refers to number of species observed in a given year.
** Average number of abundant species observed per year (Ludwig and Reynolds 1988).
*** Weires and Chiang did not differentiate between parasitoid species parasitizing *P. xylostella.*
† No *T. ni* collected.
‡ No *P. xylostella* collected.
§ Data collected from small plots surrounded by soybeans.

dence of *P. pecosensis* declined. In addition, the parasitism rate of *C. glomerata* declined throughout 1998-2003, following the detection of *C. concinnata. Compsilura concinnata* has a wide host range, parasitizing over 150 lepidopteran species (Strazanac et al. 2001), and was originally introduced into the U.S. in 1906 to control gypsy moth, *Lymantria dispar* (L.). In addition, multiple releases were made throughout the eastern U.S. until 1986. During the years of 1937, 1971-1977 and 1983, the Minnesota Department of Agriculture released *C. concinnata,* most likely to help suppress populations of the fall cankerworm, *Alsophila pometaria* (Harris), which was a major defoliator in Minnesota (J. Luhman, MDA, personal communication). Throughout the release period, researchers in the eastern U.S. documented that *C. concinnata* parasitized several lepidopteran species (e.g., Culver 1919, Boettner et al 2000, Kellogg et al. 2003). Specifically, there is concern that *C. concinnata* may be causing the decline of native saturniid moths in the eastern U.S. (Boettner et al. 2000, Kellogg et al. 2003). Culver (1919) noted that because *C. concinnata* undergoes three to four

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generations, and that the gypsy moth is univoltine, *C. concinnata* must find alternate hosts for the generations when gypsy moth larvae are not available. Because gypsy moth is not widespread in Minnesota, it is not surprising that *T. ni* and *P. rapae* have become targets of *C. concinnata.* Although *C. concinnata* is providing significant levels of biological control against these two economic pests, it is unclear how its presence will continue to alter the parasitoid complex in the future.

In summary, we have found that the species composition of larval and pupal parasitoids of *T. ni* and *P. rapae* has changed significantly since the assessment provided by Weires and Chiang (1973). We also observed the arrival of a new species, *C. concinnata,* attacking both *T. ni* and *P. rapae,* and documented the establishment of *C. rubecula* on *P. rapae.* Although the number of parasitoids associated with *P. xylostella* remained relatively unchanged since 1968, mean parasitism rates of *P. xylostella* dramatically increased to an average of 76%. In addition, although the average parasitism rate of *P. rapae* remained fairly unchanged since 1968, parasitism rates of *T. ni* increased 10-fold to an average of 39.8%. With an increase in parasitism of *T. ni,* yet unchanged parasitism for *P. rapae,* the results affirm the need to assess biological control impacts for each targeted pest species. In addition, continual monitoring of the parasitoid complex for each lepidopteran pest is necessary to determine priorities for future biological control and IPM research for cabbage, and to assess potential adverse implications associated with the introduced parasitoids *C. concinnata* and *C. rubecula.*

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