Chapter 2
Parasitoids of Oilseed Rape Pests in Europe: Key Species for Conservation Biocontrol

Bernd Ulber, Ingrid H. Williams, Zdzislaw Klukowski, Anne Luik, and Christer Nilsson

Abstract The six most important pests of oilseed rape are host to at least 80 species of parasitoid, mostly parasitic Hymenoptera, particularly braconids, chalcids and ichneumonids. Most of them attack the egg or larval stages of their hosts. Based on reviews of the literature and extensive sampling programmes during the EU project MASTER (QLK5-CT-2001-01447), 12 species have been identified as the key parasitoid species of these pests in winter oilseed rape, and, with little divergence, also in spring rape in nearly all European countries where their hosts occur. Some key species have been recorded for the first time in individual partner countries. They are sufficiently widespread and abundant across Europe to be of potential economic importance for conservation biological control of the target pests. Their incidence and abundance in European countries were associated with the occurrence of their hosts, thereby indicating close host-parasitoid-relationships.

New information on the identity, biology, phenology, distribution and impact of key parasitoid species in Europe was obtained by strategic research of the MASTER project. The level of parasitism of target pests was determined from samples of numerous field experiments and commercial crops of oilseed rape by dissection of larvae and by rearing adult parasitoids from their hosts. Percent parasitism of target pests varied between countries and years, commonly ranging between 20 and 50%, occasionally exceeding 80%.

2.1 Introduction

Parasitoids of various hymenopteran families form a substantial part of the natural enemy complex of the insect pests of oilseed rape (*Brassica napus* L.) and related species in Europe. Published literature on these parasitoids was first collated by participants of the EU-funded project BORIS, and published as detailed reviews by European authorities in Alford (2003).

B. Ulber (✉)
Department of Crop Sciences, Plant Pathology and Crop Protection Division, Georg-August University Göttingen, Göttingen, D-37077, Germany
e-mail: bulber@gwdg.de

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Here we review the identity, status and potential of parasitoids for conservation biocontrol of the pests. The information presented was largely obtained through collaborative research in six European countries (Estonia, Finland, Germany, Poland, Sweden and the UK) within the EU-funded project MASTER (Management Strategies for European Rape pests, QLK5-CT-2001-01447) during 2002–2006 (Williams et al. 2005, Williams 2006a). The project focussed on the six most widespread and economically-important insect pests of winter rape, namely the pollen beetle, *Meligethes aeneus* (Fabricius), the cabbage seed weevil, *Ceutorhynchus obstrictus* (Marsham) syn. *C. assimilis* (Paykull), the brassica pod midge, *Dasineura brassicae* (Winnertz), the cabbage stem flea beetle, *Psylliodes chrysocephala* (Linnaeus), the cabbage stem weevil, *Ceutorhynchus pallidactylus* (Marsham), and the rape stem weevil, *Ceutorhynchus napi* (Gyllenhal). It identified 11 key species of parasitoid from the parasitoid complex that were both abundant and widespread on winter rape crops throughout Europe and consequently had most potential for conservation biocontrol of these pests on winter rape (Table 2.1). Although the focus of the MASTER project was winter rape, some observations on these target pests and their parasitoids were also made in spring rape, and a further parasitoid species was identified as a key species primarily on spring

Table 2.1 Key larval parasitoids of the six most important pests of oilseed rape found during research of the EU-project 'MASTER' in the UK, Sweden (SE), Estonia (EE), Poland (PL) and Germany (DE)

Pest	Parasitoid	UK	SE	EE	PL	DE
Pollen beetle (*Meligethes aeneus*)	*Phradis interstitialis*	*	*	**	*	*
	Phradis morionellus	*	*	**	*	*
	Tersilochus heterocerus	*	*	**	*	*
	Diospilus capito	*	*	**	*	*
Cabbage seed weevil (*Ceutorhynchus obstrictus* syn. *C. assimilis*)	*Trichomalus perfectus*	*	*	**	*	*
	Mesopolobus morys	*	*	**	*	*
	Stenomalina gracilis	*	*	**	*	*
Brassica pod midge (*Dasineura brassicae*)	*Omphale clypealis*	*	*	–[1)]	–	*
	Platygaster subuliformis	*	**	*[1)]	*	**
Cabbage stem flea beetle (*Psylliodes chrysocephala*)	*Tersilochus microgaster*	**	**	–[1)]	**	*
Cabbage stem weevil (*Ceutorhynchus pallidactylus*)	*Tersilochus obscurator*	*	*	**	*	*
Rape stem weevil (*Ceutorhynchus napi*)	*Tersilochus fulvipes*	–[1)]	–[1)]	–[1)]	*	*

* = Parasitoid present in country.
** = Parasitoid associated with this pest for 1st time by MASTER.
– = Parasitoid not present in the country.
[1)] = Pest not present in the country.

rape. The importance of parasitoids for biocontrol of the pests of spring rape, particularly *Phyllotreta* flea beetles, is further reviewed by Ekbom (Chapter 5 this volume).

Pest and parasitoid activity in crops of oilseed rape (mostly winter rape but some spring rape too) was monitored for 4 years (2002–2006) in Estonia, Germany, Poland, Sweden and the UK, using yellow water traps placed and maintained at canopy level in the crop. Traps were mostly emptied three times each week. The datasets provided information on the phenology of pest and parasitoid migration into crops and their activity densities within them (see also Johnen et al. Chapter 15 this volume). Data on levels of parasitism found on both commercial crops and on unsprayed experimental plots in Estonia, Germany, Poland, Sweden and the UK between 1995 and 2005 were also collated and compared. Samples of pest larvae were collected either from plant samples or in water-filled trays below the crop canopy as they dropped to the ground to pupate. Standardized methods were used for determining levels of larval parasitism (Williams et al. 2003). Percentage endoparasitism of pollen beetle, stem weevil and cabbage stem flea beetle larvae was assessed either by dissection of host larvae and/or by rearing adult parasitoids from them (see also Klingenberg and Ulber 1994, Barari et al. 2004). Percentage ectoparasitism of cabbage seed weevil larvae was assessed by examining host larvae in pods. Percentage parasitism of brassica pod midge larvae was not determined.

Hymenopteran parasitoids are difficult to identify to species and taxonomic keys and literature on the different taxa are widely dispersed. To aid their identification, a practical, simple to use guide was produced for use by MASTER project partners (see Ferguson et al. Chapter 3 this volume). This collates essential information on the taxonomic characters of the key parasitoids from the literature, adding information obtained during the examination of thousands of parasitoid specimens collected and examined during the course of the MASTER project. It is liberally illustrated to highlight characteristic features of each key species enabling them to be distinguished from similar species by a non-specialist.

2.2 Parasitoids of the Pollen Beetle (*Meligethes aeneus*)

2.2.1 Identity of Species

The eggs or larvae of the pollen beetle in Europe are parasitized by at least nine species of hymenopteran endoparasitoid: four species of ichneumonid, three braconid, one encyrtid and one proctotrupid (Nilsson 2003, Table 2.2). Of these, *Phradis interstitialis*, *Phradis morionellus* (Fig. 2.1) and *Tersilochus heterocerus* (Fig. 2.2) are the most widespread and abundant and were identified by research within the MASTER project as the key larval parasitoids of this pest, particularly on winter rape (Table 2.1) (Williams et al. 2005, Ulber et al. 2006b). In addition, the braconid endoparasitoid, *Diospilus capito*, was found to parasitize pollen beetle

Table 2.2 Systematic list and classification of the parasitoids of the pollen beetle (*Meligethes aeneus*) reported in Europe

Order HYMENOPTERA
Superfamily ICHNEUMONOIDEA
Family ICHNEUMONIDAE (Subfamily TERSILOCHINAE)
Aneuclis Förster
– *incidens* (Thomson)
Phradis Holmgren
– *interstitialis* (Thomson)
– *morionellus* (Holmgren)
Tersilochus Holmgren (= *Thersilochus* Holmgren)
– *heterocerus* Thomson
Family BRACONIDAE (Subfamily HELCONINAE)
Blacus Nees
– *nigricornis* Haeselbarth
Diospilus Haliday
– *capito* (Nees)
Eubazus Nees (= *Calyptus* Haliday)
– *sigalphoides* (Marshall)
Superfamily CHALCIDOIDEA
Family ENCYRTIDAE
Cerchysiella Girault (= *Zeteticontus* Silvestri)
– *planiscutellum* (Mercet)
Superfamily PROCTOTRUPOIDEA
Family PROCTOTRUPIDAE
Brachyserphus Hellén
– *parvulus* (Nees)

larvae on winter rape but, more frequently, to be both abundant and widespread on spring rape. The other five parasitoids listed in Table 2.2 are of minor importance; they have been observed only occasionally with low levels of parasitism of pollen beetle larvae (Nilsson 2003). No parasitoids of the adult stage of the pollen beetle are known (Nilsson 2003).

Fig. 2.1 *Phradis morionellus*, a key parasitoid of the pollen beetle (Photo: Rothamsted Research)

Fig. 2.2 *Tersilochus heterocerus*, a key parasitoid of the pollen beetle (Photo: Rothamsted Research)

2.2.2 Distribution of Species

The key species, *P. interstitialis, P. morionellus* and *T. heterocerus*, are widely distributed throughout Europe wherever oilseed rape is grown (Nilsson 2003), including all countries contributing to the MASTER project (Table 2.3). Their occurrence and relative abundance is affected by the climate, the type of rape grown in the area and how it is cultivated (see also Nilsson Chapter 11 this volume). In central Europe and the UK, the most abundant species on winter rape are *P. interstitialis* and *T. heterocerus* (Wyrostkiewicz and Blazejewska 1985, Klingenberg and

Table 2.3 Occurrence of parasitoids of the pollen beetle (*Meligethes aeneus*) in UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family ICHNEUMONIDAE										
Aneuclis incidens			*				*		*	
Phradis interstitialis	*	*	*		*	*	*	*	*	*
Phradis morionellus	*	*	*	*	*	*	*	*	*	*
Tersilochus heterocerus	*	*	*	*	*	*	*	*	*	*
Family BRACONIDAE										
Blacus sp.	*	*	*			*	*			
Blacus nigricornis			*			*	*		*	*
Diospilus capito	*		*	*	*	*	*	*	*	*
Eubazus sigalphoides							*			
Family ENCYRTIDAE										
Cerchysiella planiscutellum	*									
Family PROCTOTRUPIDAE										
Brachyserphus parvulus	*	*	*			*			*	

L = reported in the literature; R = reared from the host during the MASTER project or, in Estonia, caught in yellow water traps.

Ulber 1994, Büchi 2002, Kraus and Kromp 2002, Nilsson 2003, Ferguson et al. 2003) whereas in northern Europe (Estonia, Finland and Central Sweden) where more spring rape is grown, *P. morionellus* is often the more abundant (Hokkanen 1989, Billqvist and Ekbom 2001a, Nilsson 2003, Jönsson et al. 2004, Hokkanen 2006, Veromann et al. 2006b, d). In Estonia, although all four key parasitoids have been caught from spring rape, only *Phradis morionellus* has so far been caught from winter rape (Veromann et al. 2006c).

The braconid *D. capito* is also widely distributed throughout Europe wherever oilseed rape is grown and has also been reported from all MASTER countries (Nilsson 2003, Williams et al. 2005, Table 2.3). However, like *P. morionellus,* it is a more common parasitoid of pollen beetle larvae in northern Europe (Estonia, Finland, Sweden), particularly on spring rape (Nilsson and Andreasson 1987, Billqvist and Ekbom 2001b, Nilsson 2003, Veromann et al. 2006c, Hokkanen 2008). Populations on winter rape are generally low (Nilsson 2003). In Estonia, however, *D. capito* is a major parasitoid of pollen beetle larvae on both winter and spring rape (Luik et al. 2006); this may be due to the delayed phenology of host larvae on winter crops in this country. Numbers of *D. capito* caught in yellow water traps in Estonia increased with expansion of the area grown to winter rape (Veromann et al. 2006a).

Parasitism of pollen beetle larvae by *Aneuclis incidens*, *Blacus nigricornis*, *Brachyserphus parvulus*, *Cerchysiella planiscutellum* and *Eubazus sigalphoides* has been recorded infrequently and from various European countries; few specimens are generally found although *B. parvulus* and *B. nigricornis* can be common in some crops (Nilsson 2003).

The within-field spatio-temporal distributions of the pollen beetle and its key parasitoids are reviewed by Williams and Ferguson (Chapter 8 this volume).

2.2.3 Life Histories of Key Species

The life histories of the three key ichneumonid parasitoid species attacking pollen beetle larvae, namely *P. interstitialis, P. morionellus* and *T. heterocerus*, have been studied in detail by Jourdheuil (1960), Osborne (1960) and Nilsson (1994, 1997), and are reviewed by Nilsson (2003). They are all univoltine, koinobiont endoparasitoids. They overwinter as diapausing adults within their pupal cocoons in the soil of fields that have just grown oilseed rape. Overwintering mortality can be high and adversely affected by soil tillage (Nilsson 1985, 1989; Nilsson Chapter 11 this volume). The time of emergence and migration to new crops of oilseed rape the following spring varies between species, regions and years being dependent on weather parameters, particularly temperature and sunshine (see Johnen et al. Chapter 15 this volume). Adults of *P. interstitialis* often emerge 1–2 weeks earlier than the other two species, in early to mid-April, and may be found in rape crops already at the bud stage (Ulber and Nitzsche 2006, Williams 2006b). Female *P. interstitialis* prefer to oviposit through the bud walls into the eggs and first-instar larvae of their hosts (Nilsson 2003). Adults of *P. morionellus* and *T. heterocerus* commonly colonize the crop at the beginning of flowering, i.e., towards the end of April or early May in Germany and UK (Ulber and Nitzsche 2006, Williams 2006b). They oviposit into small larvae within buds and large second instar host larvae in open flowers, respectively (Nilsson 2003). Female parasitoids are attracted by volatiles emitted by oilseed rape (Jönsson et al. 2005, Williams et al. 2007; Williams and Cook Chapter 7 this volume). Following eclosion, the parasitoid remains in its first instar until the full-grown host larva drops to the ground to pupate. There, the parasitoid completes its larval development in a few days and finally kills the prepupal stage of its host. Pupation of the parasitoid larva occurs within the earthen cocoon of its host. Adults then diapause in their silken cocoons and emerge from the soil the following spring.

The braconid *D. capito* is a multivoltine koinobiont larval endoparasitoid with two to three generations per year in Northern Europe (Billqvist and Ekbom 2001b, Nilsson 2003). Host alternation between the pollen beetle and other beetle species was suggested by Meuche (1940) and Börner et al. (1942), but, in France, no other host of *D. capito* was found (Jourdheuil 1960). Adult *D. capito* often first appear in low numbers towards the end of flowering of winter rape, but are more numerous during flowering of spring rape (Börner et al. 1921, Kaufmann 1923, Miczulski 1967). Females oviposit in both first and second instar host larvae, in buds as well as flowers (Börner and Blunck 1920, Osborne 1960). New generation adults emerge from the soil approximately 10 days after migration of their host larvae into the soil to pupate. Few adults are thought to survive winter (Nilsson 2003).

In a recent survey (2007) at various locations in Germany, parasitism of pollen beetle larvae by *P. interstitialis* and *T. heterocerus* was observed from mid April to the end of June, while parasitism by *D. capito* was found only on spring rape from the end of May to mid August (Krueger and Ulber unpublished).

2.2.4 Percentage Parasitism

Parasitism of pollen beetle larvae can be a major factor for the population dynamics of this pest. Levels of parasitism exceeding 50% have been reported recently from several European countries, e.g., Austria (Kromp and Kraus 2006), Finland (Hokkanen 2006), Germany (Nitzsche 1998), Sweden (Nilsson 1989), Switzerland (Büchi 2002) and the UK (Williams 2006b).

Data collated during the MASTER project showed that parasitism of pollen beetle larvae from unsprayed crops of winter rape under various growing conditions for the years 1995–2005 (Ulber et al. 2006b) was often high, up to 97%, with average levels in Germany, Poland, Sweden and the UK within the range 25–50% (Fig. 2.3). In Estonia, percentage parasitism was lower (3–18%). In spring rape, similar high levels of parasitism as in winter rape were observed in Sweden and the UK (Fig. 2.4), but, in contrast, in Estonia and in Germany they were lower, between 0 and 16%. The relative abundance of the key parasitoids varied between countries. *Tersilochus heterocerus* and *P. interstitialis* predominated in Germany, Poland and the UK, while *P. morionellus* and *D. capito* were more common in Estonia and in Central Sweden.

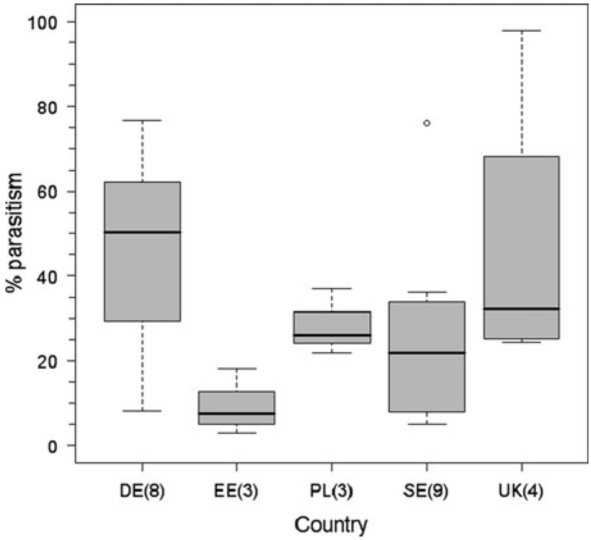

Fig. 2.3 Percentage larval parasitism of the pollen beetle, *Meligethes aeneus*, in crops of winter oilseed rape in Germany (DE), Estonia (EE), Poland (PL), Sweden (SE) and the UK in 1995–2005. In parentheses: number of oilseed rape crops examined

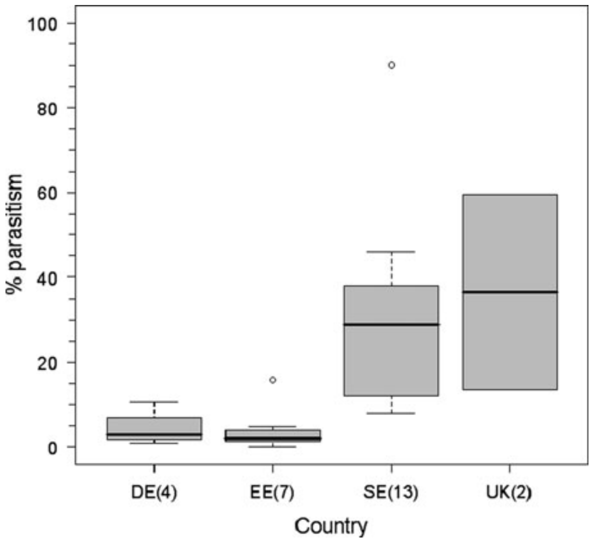

Fig. 2.4 Percentage larval parasitism of the pollen beetle, *Meligethes aeneus*, in crops of spring oilseed rape in Germany (DE), Estonia (EE), Sweden (SE) and the UK in 1995–2005. In parentheses: number of oilseed rape crops examined

Hokkanen (2008) studied parasitism of pollen beetle larvae by *P. morionellus* on spring rape crops in 13 regions of Finland from 1985 to 1995. The percentage of parasitism in each region weighted by the area of rape grown in the region was used as a measure for the proportion of pollen beetles removed from the new generation; it ranged from 8% in 1988 to 49% in 1987, with average levels between 20 and 40% in other years. By comparison with damage severity levels by the pollen beetle in these regions, Hokkanen concluded that parasitoids were able to significantly lower beetle abundance when 30–40% larval parasitism was exceeded.

Superparasitism, that is, more than one parasitoid egg or larva per pollen beetle larva, is common with *T. heterocerus* but not with *P. interstialis* (Nitzsche 1998). It was observed regularly even at parasitisation rates as low as 4% (Ulber unpublished). When the overall level of parasitism was very high, e.g., at 97% in the UK (Williams 2006b), the level of superparasitism was as high as 95%. Further, multiparasitism, that is, host larvae with more than one species of parasitoid, occurs frequently with both *T. heterocerus* and *Phradis* spp. but only one parasitoid develops to adult within each larva (Nitzsche 1998); thus parasitoid species are essentially competitors. Female *T. heterocerus* do not discriminate between host larvae that are already parasitized, either by conspecifics or by *Phradis* spp., and non-parasitized host larvae (Nitzsche 1998).

The braconid *D. capito* parasitised pollen beetle larvae on winter rape only occasionally during the MASTER project, but was more frequently found on spring rape crops in Estonia, Finland, Germany, Sweden and the UK. Other studies have found levels of pollen beetle larval parasitism of 8–29% on white mustard and spring rape in Sweden (Billqvist and Ekbom 2001b), 5–12% on spring rape in Finland (Hokkanen 1989) and 3–16% on spring rape in Germany (Krueger and Ulber unpublished).

2.3 Parasitoids of Cabbage Seed Weevil (*Ceutorhynchus obstrictus* syn. *C. assimilis*)

2.3.1 Identity of Species

The cabbage seed weevil is host to at least 31 species of parasitoid (Table 2.4), mostly larval ectoparasitoids, of which three pteromalids, *Trichomalus perfectus* (Fig. 2.5), *Stenomalina gracilis* (Fig. 2.6) and *Mesopolobus morys* (Fig. 2.7) dominate. Where ectoparasitoids from seed weevil larvae have been reared to adults (e.g., Laborius 1972, Murchie 1996, Ulber and Vidal 1998, Kevväi et al. 2006), *T. perfectus* has usually been the predominant species, followed by *M. morys* and then *S. gracilis*. *Mesopolobus morys* may be relatively more important on spring than on winter rape (Murchie 1996). These three species were identified as key species for biocontrol in Europe by the MASTER project (Table 2.1, Ulber et al. 2006b); other larval parasitoids appear to be insufficiently widespread or abundant to contribute much to biocontrol of this pest. The adult weevil is parasitized by the braconid *Microctonus melanopus*, a species which can be abundant locally (Bonnemaison 1957, Jourdheuil 1960). Mymarids are known to attack the eggs, but also appear to be of negligible importance for biocontrol (Williams 2003a).

Table 2.4 Systematic list and classification of the parasitoids of cabbage seed weevil (*Ceutorhynchus obstrictus* syn. *C. assimilis*) reported in Europe

Order HYMENOPTERA
Superfamily ICHNEUMONOIDEA
Family ICHNEUMONIDAE (Subfamily TERSILOCHINAE)
Aneuclis Förster
– *melanaria* (Holmgren) (= *diversus* Szépligeti; = *petiolaris* Szépligeti)
Tersilochus Holmgren
– sp.
Family BRACONIDAE (Subfamily DORYCTINAE)
Bracon Fabricius
– *fulvipes* Nees
– sp.
– *variator* Nees (= *discoideus* Wesmael [Note 1]; = *maculiger* Wesmael)
Family BRACONIDAE (Subfamily CHELONINAE)
Sigalphus Latreille
– *obscurellus* Nees
Family BRACONIDAE (Subfamily HELCONINAE)
Diospilus Haliday
– *morosus* Reinhardt
– *oleraceus* Haliday
Taphaeus Wesmael
– *affinis* Wesmael
Family BRACONIDAE (Subfamily EUPHORINAE)
Microctonus Wesmael
– *melanopus* Ruthe [also cited as *Perilitus melanopus*]
– cf. *deceptor* Wesmael
Superfamily CHALCIDOIDEA
Family EURYTOMIDAE
Eurytoma Illiger
– *aciculata* (Ratzeburg) [hyperparasitoid]
– *curculionum* Mayr
– sp.
Family PTEROMALIDAE (Subfamily PTEROMALINAE)
Anisopteromalus Ruschka
– *calandrae* (Howard)
Chlorocytus Graham
– *diversus* (Walker)
Habrocytus Thomson
– *dispar* (Curtis)
– *semotus* (Walker)
Mesopolobus Westwood = *Amblymerus* Walker; = *Eutelus* Walker; = *Xenocrepis* (Förster)
– *mediterraneus* (Mayr) [hyperparasitoid]
– *morys* (Walker) (= *pura* Mayr)
Stenomalina Ghesquière
– *gracilis* (Walker) = *muscarum* (Linnaeus)
Trichomalus Thomson
– *perfectus* (Walker) = *decisus* (Walker); = *decorus* (Walker); = *laevinucha* (Thomson)
– sp.
Zatropis Crawford
– sp.

Table 2.4 (continued)

Family EUPELMIDAE (Subfamily EUPELMINAE)
Eupelmus Dalman (= *Eupelmella* Masi; = *Macroneura* Walker)
– *vesicularis* (Retzius)
Family EULOPHIDAE
Eulophus Müller
– sp.
Necremnus Thomson
– *tidius* (Walker) (= *duplicatus* Gahan)
Tetrastichus Haliday
–*galectobus* (Ratzeburg)
Family MYMARIDAE (Subfamily MYMARINAE)
Anaphes Haliday
– *fuscipennis* Haliday
Mymar Curtis
– *autumnalis* (Förster)
Patasson Walker
– *brachygaster* Debauche
– *declinata* (Soyka)

NB Some authorities treat *Bracon discoideus* Wesmael as a separate species.

Fig. 2.5 *Trichomalus perfectus*, a key parasitoid of the cabbage seed weevil (Photo: Rothamsted Research)

Fig. 2.6 *Stenomalina gracilis*, a key parasitoid of the cabbage seed weevil (Photo: Rothamsted Research)

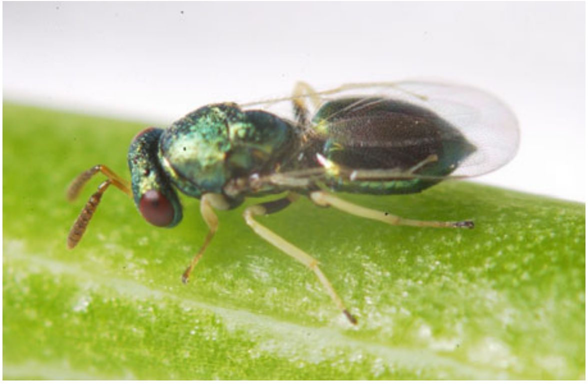

Fig. 2.7 *Mesopolobus morys*, a key parasitoid of the cabbage seed weevil (Photo: Rothamsted Research)

2.3.2 Distribution of Species

The three key parasitoid species, *T. perfectus*, *S. gracilis* and *M. morys*, are widely distributed throughout Europe (Williams 2003a). They were found in all five countries monitored during the MASTER project (Table 2.5). Other species of parasitoid have been infrequently reported from one or more countries but are not widespread (Williams 2003a, Table 2.5).

Literature on the within-field spatio-temporal distributions of the cabbage seed weevil and its key parasitoids is reviewed by Williams and Ferguson (Chapter 8 this volume).

2.3.3 Life Histories of Key Species

The three key pteromalid species attacking cabbage seed weevil larvae are thought to have similar life-histories, although only *T. perfectus* has been studied in detail (Dmoch and Klimek 1975, Murchie 1996, for a review see Williams 2003a).

Trichomalus perfectus is a univoltine ectoparasitoid with peaks of abundance on crops of oilseed rape 2–4 weeks after immigration of its host. More detailed information on its immigration phenology in relation to weather parameters is presented by Johnen et al. (Chapter 15 this volume). On locating a seed weevil larva within a pod, the female penetrates the pod with her ovipositor and lays a single egg on its surface. The parasitoid is a solitary idiobiont, so the host larva is immobilised on parasitisation and gradually discolours. The parasitoid egg hatches in 1–4 days and the larva feeds externally from its host for 7–10 days, eventually consuming it completely, except for its head capsule and skin. It pupates alongside its host's remains without forming a cocoon; the pupal stage lasts 8–15 days. The adult chews a small hole in the pod wall through which it exits the pod. New generation adults mate at emergence and can be found on the crop until harvest time. Only females are thought to overwinter, probably in evergreen foliage and other sheltered places. In addition

Table 2.5 Occurrence of parasitoids of the cabbage seed weevil (*Ceutorhynchus obstrictus* syn. *C. assimilis*) in the UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family BRACONIDAE										
Bracon variator							*			
Sigalphus obscurellus	*									
Diospilus oleraceus	*						*		*	
Microctonus sp.	*	*								
Microctonus melanopus									*	
Microctonus cf. deceptor							*			
Family EURYTOMIDAE										
Eurytoma aciculata							*			
Eurytoma curculionum		*					*	*	*	*
Family PTEROMALIDAE										
Chlorocytus diversus	*									
Habrocytus sp.							*	*		
Habrocytus semotus	*									
Mesopolobus morys	*	*	*	*	*	*	*	*	*	*
Stenomalina gracilis	*	*	*	*	*	*	*	*	*	*
Trichomalus perfectus	*	*	*	*	*	*	*	*	*	*
Family EUPELMIDAE										
Eupelmus vesicularis							*	*		
Family EULOPHIDAE										
Necremnus sp.	*								*	
Necremnus tidius							*			
Tetrastichus galectobus	*									
Family MYMARIDAE										
Anaphes sp.						*	*			
Anaphes fuscipennis							*			
Mymar autumnalis									*	
Patasson sp.							*			
Patasson brachygaster	*									

L = species or genus reported in literature; R = species or genus reared from host.

to killing the larvae by parasitisation, *T. perfectus* can cause substantial mortality of host larvae by host-feeding.

2.3.4 Percentage Parasitism

Variable levels of parasitism of seed weevil larvae have been reported in the literature and they can be substantial (Williams 2003a) e.g., exceeding 50% in Germany (Nissen 1997), in Switzerland (Linz 1991, Büchi 1993) and the UK (Murchie 1996), thereby contributing to biocontrol of this pest.

Parasitism of seed weevil larvae from unsprayed crops of winter rape under various growing conditions in four European countries during the MASTER project

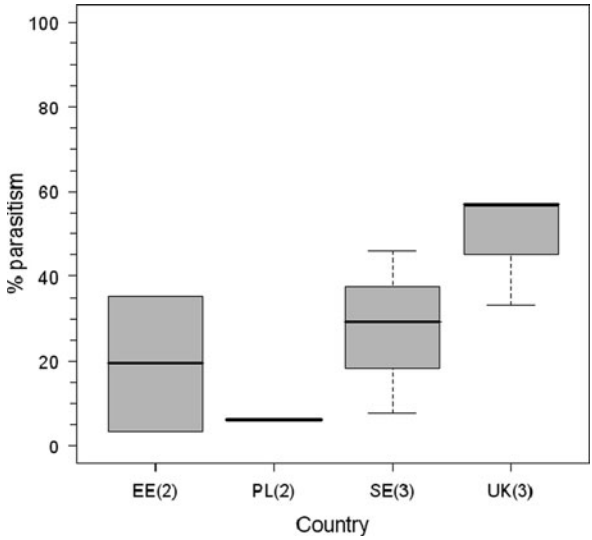

Fig. 2.8 Percentage larval parasitism of the cabbage seed weevil, *Ceutorhynchus obstrictus* syn. *C. assimilis*, in crops of winter oilseed rape, in Estonia (EE), Poland (PL), Sweden (SE) and the UK, in 1995–2005. In parentheses: number of oilseed rape crops examined

(Ulber et al. 2006b) ranged from 3–35% in Estonia to 33–57% in the UK (Fig. 2.8). In six of the 10 crops studied, percentage parasitism exceeded 30%. However, in two crops studied in Poland, parasitism was only 6%. In all four countries, *T. perfectus, M. morys* and *S. gracilis* were the only species of parasitoid found to attack seed weevil larvae during the MASTER project.

2.4 Parasitoids of the Brassica Pod Midge (*Dasineura brassicae*)

2.4.1 Identity of Species

The brassica pod midge is reported in the literature to be host to at least 31 species of parasitoid, all attacking the egg and larval stages (Williams and Walton 1990, Williams 2003b, Table 2.6). Of these, the platygastrid *Platygaster subuliformis* (Fig. 2.9) and the eulophid *Omphale clypealis* (Fig. 2.10) have been recorded most commonly in Europe and were identified as key parasitoid species during the MASTER project (Table 2.1). No parasitoids have been reported to attack the adults (Williams 2003b).

Platygaster subuliformis appears to be the most widespread parasitoid of the brassica pod midge in Europe (Williams 2003b, Ulber et al. 2006b). The species is described by Murchie et al. (1999); they found it to be the most important parasitoid of the larvae in the UK, and a new species record for the country. During the MASTER project it was also found to be the dominant species parasitizing brassica pod midge in Germany, Sweden and Poland (Ulber et al. 2006b). Identification of *Platygaster* specimens to species is difficult; *P. subuliformis* can be easily confused

Table 2.6 Systematic list and classification of the parasitoids of brassica pod midge (*Dasineura brassicae*) reported in Europe

Order HYMENOPTERA
Superfamily CHALCIDOIDEA
  Family EURYTOMIDAE
    Eurytoma Illiger
    – *aciculata* Ratzeburg
    – *dentata* Mayr
  Family TORYMIDAE
    Pseudotorymus Masi
    – *napi* Amerling & Kirchner (= *brassicae* Ruschka)
  Family EULOPHIDAE
    Aprostocetus Westwood
    – *epicharmus* (Walker) (= *variegatus* Szelényi)
    Necremnus Thomson
    – *leucarthros* (Nees)
    Neochrysocharis Kurdjumov
    – sp.
    Omphale Haliday (= *Secodes* Förster)
    – *clypealis* (Thomson)
    – *coilus* (Walker)
    Sigmophora Rondani
    – *brevicornis* (Panzer)
Superfamily PLATYGASTROIDEA
  Family PLATYGASTRIDAE
    Amblyaspis Förster
    – sp.
    Inostemma Haliday
    – *boscii* (Jurine)
    – *walkeri* Kieffer
    – nr *reticulatum* (Szelényi)
    Isocybus Förster
    – *thomsoni* Kieffer
    Piestopleura Förster
    – sp.
    Platygaster Latreille (= *Prosactogaster* Kieffer)
    – *boscii* Nees
    – *gladiator* Zetterstedt
    – *iolas* Walker
    – *munita* Walker
    – *niger* Nees
    – *nitida* (Thomson)
    – *oebalus* Walker
    – *subuliformis* (Kieffer)
    – *tisias* Walker
    Synopeas Förster
    – nr *lugubris* Thomson
    – sp.
Superfamily CERAPHRONOIDEA
  Family CERAPHRONIDAE
    Aphanogmus Thomson
    – *abdominalis* (Thomson)
    – *tenuicornis* Thomson

Table 2.6 (continued)

Ceraphron Jurine = *Calliceras* Nees
– *longipennis* (Kieffer) (= *insularis* (Kieffer))
– *pallipes* Thomson
– *serraticornis* Kieffer
– *xanthosoma* (Kieffer)
Family MEGASPILIDAE
Conostigmus Dahlborn
– *rufescens* Kieffer

Fig. 2.9 *Platygaster subuliformis*, a key parasitoid of the brassica pod midge (Photo: Rothamsted Research)

Fig. 2.10 *Omphale clypealis*, a key parasitoid of the brassica pod midge (Photo: Rothamsted Research)

with *P. minuta, P. gladiator, P. oebalus and P. tisias* (Murchie et al. 1999). Therefore, former records of other species of *Platygaster* and *Prosactogaster* in the literature (e.g., Laborius 1972) may be misidentifications and may refer to *P. subuliformis* as well.

A study of the parasitoid complex attacking brassica pod midge in the UK recorded only *P. subuliformis* and *O. clypealis* from winter rape but a further two species (an *Aphanogmus* sp. and a *Ceraphron* sp.) from spring rape (Murchie 1996).

Platygaster subuliformis was the more abundant on winter rape whereas *O. clypealis* was the more abundant on spring rape.

2.4.2 Distribution of Key Species

Platygaster spp. and *O. clypealis* are both widespread in distribution throughout northern and central Europe and probably occur almost everywhere that their host species exists whereas all other species have been reported from only a few countries and are infrequently encountered (Williams 2003b, Table 2.7). The key species

Table 2.7 Occurrence of parasitoids of the brassica pod midge (*Dasineura brassicae*) in the UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family EURYTOMIDAE										
Eurytoma aciculata							*	*		
Eurytoma dentata							*			
Family TORYMIDAE										
Pseudotorymus napi							*	*	*	
Family EULOPHIDAE										
Aprostocetus epicharmus	*						*	*		
Necremnus leucarthros							*	*	*	
Neochrysocharis sp.							*			
Omphale clypealis	*	*	*	*		*			*	
Omphale coilus							*	*		
Sigmophora brevicornis									*	
Family PLATYGASTRIDAE										
Inostemma sp.			*						*	
Inostemma boscii									*	
Inostemma walkeri							*	*	*	
Piestopleura sp.									*	
Platygaster sp.			*	*		*	*	*	*	
Platygaster iolas							*	*		
Platygaster nitida							*	*		
Platygaster oebalus								*	*	
Platygaster subuliformis	*	*	*	*		*		*		*
Synopeas sp.			*	*						
Family CERAPHRONIDAE										
Aphanogmus sp.		*	*							
Aphanogmus abdominalis							*	*	*	
Ceraphron sp.		*	*	*						
Ceraphron pallipes									*	
Ceraphron serraticornis									*	
Ceraphron xanthosoma									*	
Family MEGASPILIDAE										
Conostigmus rufescens									*	

L = species or genus reported in literature; R = species or genus reared from host, or, in Estonia, caught in yellow water traps.

P. subuliformis appears to be the most widely distributed and abundant; it occurred in all countries participating in the MASTER project (Table 2.7). The key species *O. clypealis* was found in all MASTER countries except Poland. Surprisingly, both species were caught in yellow water traps in crops of oilseed rape in Estonia, although their host, the brassica pod midge, has not been recorded there (Veromann et al. 2006c).

The within-field, spatio-temporal distributions of the brassica pod midge and its parasitoids is reviewed by Williams and Ferguson (Chapter 8 this volume).

2.4.3 Life Histories of Key Species

Literature on the life histories and biology of both key species of parasitoid attacking the brassica pod midge is reviewed by Williams (2003b). Information about their responses to host plant volatiles is presented in Williams and Cook (Chapter 7 this volume).

Platygaster subuliformis is an egg-larval endoparasitoid (Murchie et al. 1999). Like its host it is probably multivoltine, although it may have fewer generations per year than its host as it takes longer to emerge pre-diapause. Emergence in the UK occurs during the first half of May with peak abundance of adults co-inciding with peak availability of host larvae (Ferguson et al. 2004). Each female parasitizes several host eggs within an infested pod, laying a single egg in each. The parasitoid is a koinobiont; its egg develops only after its host is nearly full-grown and at the prepupal and pupal stage of development within the host's larval skin. Part of the population emerges the same season, part remains in diapause in the soil inside host cocoons. Mating occurs soon after emergence and the mated females then migrate to rape crops. Further information on the phenology of its migration to winter rape in relation to weather parameters is presented in Johnen et al. (Chapter 15 this volume).

Omphale clypealis is a larval endoparasitoid. Like its host, it is probably multivoltine but its biology is poorly known. It overwinters within the cocoons of its host and emerges over a prolonged period during the spring and summer, starting about a month later than its host (Ferguson et al. 2004). Its sex ratio is strongly female-biased (Murchie 1996). Peak abundance of the parasitoid has been found to co-incide with that of its host. The females oviposit into mature host larvae through the pod wall and the parasitoid larva feeds within its host during its larval and pupal stages, completing its development after the mature host larva has dropped to the soil to pupate.

2.4.4 Percentage Parasitism

The few assessments of the levels of parasitism in the brassica pod midge are difficult to compare because of the multivoltine life-histories of both pest and key parasitoids and the ability of the pest to diapause for several years. However, several studies suggest that although percentage parasitism is variable it can also be substantial in some years. Thus, Murchie (1996) found that, in the UK, *P. subuliformis* emerged pre-diapause from 3 to 13% and from 0 to 18% of host larvae collected at weekly intervals (for 4 weeks) from two crops of winter rape and from 4 to 67% and from 27 to 74% of larvae, post-diapause. Ten percent of midge cocoons from a spring rape crop were parasitized. Ferguson et al. (2004) found that, in winter rape in 1999, only 7% of first generation midge larvae, which dropped to the ground to pupate, gave rise to adult insects (midge and parasitoids) that same year, and that of these 42% were parasitoids, mostly *O. clypealis*. Only 0.2% of both generations of midge larvae emerged as adults the following year, of which 49% were parasitoids, with similar numbers of *O. clypealis* and *P. subuliformis*.

In recent years, the infestation levels of oilseed rape by the brassica pod midge have been low and parasitism levels of pod midge larvae were not estimated during the MASTER project (Ulber et al. 2006b).

2.5 Parasitoids of Stem-Mining Pests

2.5.1 Identity of Species

2.5.1.1 Parasitoids of the Cabbage Stem Flea Beetle (*Psylliodes chrysocephala*)

Three ichneumonid, two braconid and one pteromalid parasitoid species have been reared from the larvae of the cabbage stem flea beetle and one braconid from the adult in Europe (Table 2.8).

Table 2.8 Systematic list and classification of the parasitoids of the cabbage stem flea beetle (*Psylliodes chrysocephala*) reported in Europe

Order HYMENOPTERA
Superfamily ICHNEUMONOIDEA
Family ICHNEUMONIDAE
Aneuclis Förster
– *melanaria* (Holmgren) (= *diversus* Szépligeti; = *petiolaris* Szépligeti) [Note 1]
Tersilochus Holmgren (= *Thersilochus* Holmgren)
– *microgaster* (Szépligeti) [Note 2]
Family BRACONIDAE
Diospilus Haliday
– *morosus* Reinhardt
– *oleraceus* Haliday
Microctonus Wesmael
– *melanopus* Ruthe [Note 3]
Superfamily CHALCIDOIDEA
Family PTEROMALIDAE
Trichomalus Thomson
– *lucidus* (Walker)
– nr *lucidus* (Walker)

Note 1. Also cited in the literature under genera *Isugurus*, *Perilitus* and *Thersilochus.*
Note 2. Also cited in the literature as *Isurgus microgaster* Szépligeti.
Note 3. Also cited in the literature as *Perilitus melanopus* Ruthe.

Earlier studies from France (Jourdheuil 1960), Czech Republic (Šedivý 1983) and Germany (Dosse 1961, Lehmann 1965), reported that *Tersilochus tripartitus* Brischke (syn. *Tersilochus melanogaster* Thomson) was an abundant larval parasitoid of the cabbage stem flea beetle. However, since 1990, *T. tripartitus* has never been detected, and *Tersilochus microgaster* (Szépligeti) has been reported to be the most abundant and frequently occurring parasitoid of this pest in Europe (Klingenberg and Ulber 1994, Nitzsche 1998, Barari et al. 2004, Ulber and Wedemeyer 2004). Because Horstmann (pers comm) recently found that no host is known for *T. tripartitus,* the earlier reports apparently resulted from erroneous identification of *T. microgaster*. In the MASTER project, *T. microgaster* was identified as the only key larval parasitoid species for the cabbage stem flea beetle (Table 2.1). All other larval parasitoid species appear to be of minor importance (Ulber and Williams 2003).

The braconid *Microctonus melanopus* is the only species known to attack adult cabbage stem flea beetles but information on the status, importance and biology of this species is sparse (Jourdheuil 1960, Ulber and Williams 2003).

2.5.1.2 Parasitoids of the Cabbage Stem Weevil (*Ceutorhynchus pallidactylus*)

The larva of the cabbage stem weevil is host to three known parasitoid species (Table 2.9). The most abundant and widespread species is *Tersilochus obscurator*; it is the only one identified as a key species for biocontrol by the MASTER project (Table 2.1). Various species reported in the literature like *Thersilochus tripartitus* Brischke spp. *obscurator* Aubert (Aubert and Jourdheuil 1958) have proved to be synonyms of *T. obscurator* (Horstmann 1971, 1981). *Stibeutes curvispina* has been reported only from Germany; it parasitises the larvae or prepupae within the soil

Table 2.9 Systematic list and classification of the parasitoids of the cabbage stem weevil (*Ceutorhynchus pallidactylus*) reported in Europe

Order HYMENOPTERA
Family ICHNEUMONIDAE
Subfamily PHYGADEUONTINAE
Stibeutes Förster
– *curvispina* (Thomson)
Subfamily TERSILOCHINAE
Tersilochus Holmgren (= *Thersilochus* Holmgren)
– *obscurator* Aubert [Note 1]
Family BRACONIDAE
Microctonus Wesmael
– *melanopus* Ruthe [Note 2]
Family PTEROMALIDAE
Trichomalus Thomson
– *lucidus* (Walker)

Note 1. Also cited in the literature as *Thersilochus tripartitus* Brischke spp. *obscurator* Aubert.
Note 2. Also cited in the literature as *Perilitus melanopus* Ruthe.

(Nissen 1997). The multivoltine ectoparasitoid *T. lucidus* was reared from larvae of cabbage stem weevil in Poland and Germany during the MASTER project (Ulber et al. 2006b).

The braconid, *M. melanopus*, attacks the adults (Table 2.9); this species is a non-specialist and attacks the adults of the cabbage stem flea beetle, cabbage seed weevil and the rape winter stem weevil, *Ceutorhynchus picitarsis* as well (Jourdheuil 1960).

2.5.1.3 Parasitoids of the Rape Stem Weevil (*Ceutorhynchus napi*)

Only two species of parasitoid are known to parasitise the larvae of the rape stem weevil: the ichneumonid *Tersilochus fulvipes* (Jourdheuil 1960, Šedivý 1983, Ulber 2000, 2003) and the pteromalid ectoparasitoid *Stenomalina gracilis* (Table 2.10). The former is abundant and widespread and considered a key species for biocontrol (Table 2.1). The latter has been reared from rape stem weevil larvae in Poland (Klukowski and Kelm 2000); it is a key parasitoid of cabbage seed weevil larvae (Table 2.1).

Table 2.10 Systematic list and classification of the parasitoids of the cabbage stem weevil (*C. napi*) reported in Europe

Order HYMENOPTERA
  Family ICHNEUMONIDAE
    Subfamily TERSILOCHINAE
      Tersilochus Holmgren (= *Thersilochus* Holmgren)
      – *fulvipes* (Gravenhorst) (= gibbus Holmgren) [Note 1]
  Family PTEROMALIDAE
      Stenomalina Ghesquière
      – *gracilis* (Walker) (*muscarum* misidentification)

Note 1. Also cited in the literature as *Porizon fulvipes* (Gravenhorst) and as *Thersilochus fulvipes* (Gravenhorst) ssp. *gallicator* Aubert.

2.5.2 Distribution of Species

Tersilochus microgaster is the most widely distributed parasitoid of cabbage stem flea beetle in Europe. It was reared from this host for the first time in Germany (Klingenberg and Ulber 1994) and has also been identified, during the MASTER project from UK (Barari et al. 2005), Sweden and Poland (Table 2.11). It has not been reported from Estonia and Finland where its host, the cabbage stem flea beetle, is not present (Veromann et al. 2006a).

Other parasitoid species attacking cabbage stem flea beetle are less widespread on oilseed rape crops. Although *Aneuclis melanaria* has been reported from many European countries (Horstmann 1971, 1981): France (Aubert and Jourdheuil 1958, Jourdheuil 1960), Czech Republic (Šedivý 1983) and Germany (Ulber and Wedemeyer 2004), it was not found on either winter nor spring rape crops in UK, Sweden, Estonia or Poland during the MASTER project. *Cremastus carinifer*, has been reported from Germany (Meuche 1940) and France (Bonnemaison and

Table 2.11 Occurrence of parasitoids of cabbage stem flea beetle (*Psylliodes chrysocephala*) in UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family ICHNEUMONIDAE										
Aneuclis melanaria										*
Cremastus carinifer									*	
Tersilochus microgaster	*	*	*	*			*			*
Family BRACONIDAE										
Diospilus oleraceus							*		*	
Diospilus morosus							*		*	
Microctonus sp.		*					*			
Family PTEROMALIDAE										
Trichomalus lucidus							*		*	*

L = species or genus reported in literature; R = species or genus reared from host. Pest not present in Estonia

Table 2.12 Occurrence of parasitoids of the cabbage stem weevil (*Ceutorhynchus pallidactylus*) in UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family ICHNEUMONIDAE										
Tersilochus obscurator	*	*	*	*		*		*	*	*
Family BRACONIDAE										
Microctonus melanopus									*	
Family PTEROMALIDAE										
Trichomalus lucidus	*							*		*

L = species or genus reported in literature; R = species or genus reared from host. Pest not present in Estonia.

Jourdheuil 1954); however, the identification in France was later revised to *Aneuclis melanaria* (Jourdheuil 1960). *Diospilus morosus* and *D. oleraceus* have been reported from France (Jourdheuil 1960) and *D. morosus* also from Germany (Godan 1950). *Trichomalus lucidus* has been reared from the larvae of the cabbage stem flea beetle in Germany (Nissen 1997, Ulber and Wedemeyer 2004) and the UK (DV Alford *unpublished*); it has also been found to parasitise larvae of cabbage stem weevil in Germany (Ulber and Wedemeyer 2004).

Tersilochus obscurator, the key larval parasitoid of the cabbage stem weevil, has been reared from host larvae in Germany, Poland and Sweden, and now, for the first time during the MASTER project from Estonia and the UK (Table 2.12). In addition, it has been reported in the literature from Ireland, France, Switzerland, Austria, Czech Republic and Hungary (Jourdheuil 1960, Horstmann 1981, Šedivý 1983, Büchi 1995, Kraus and Kromp 2002).

Table 2.13 Occurrence of parasitoids of the rape stem weevil (*Ceutorhynchus napi*) in UK, Sweden, Estonia, Poland, and Germany

	UK		Sweden		Estonia		Poland		Germany	
Family/species	L	R	L	R	L	R	L	R	L	R
Family ICHNEUMONIDAE										
Tersilochus fulvipes								*	*	*
Family PTEROMALIDAE										
Stenomalina gracilis	*		*		*		*	*	*	

L = species or genus reported in literature; R = species or genus reared from host. Pest not present in the UK or Estonia.
NB *S. gracilis* is also a parasitoid of the cabbage seed weevil.

Tersilochus fulvipes, the key larval parasitoid of rape stem weevil, has been reported from most countries where its host occurs, including Austria (Kraus and Kromp 2002), the Czech Republic (Šedivý 1983), France (Jourdheuil 1960), Germany (Ulber 2000, 2003), Hungary (Horstmann 1981), Poland (Klukowski pers comm) and Switzerland (Günthardt 1949) and was reared from this host in Poland and Germany during the MASTER project (Table 2.13).

The within-field, spatio-temporal distributions of the stem-mining pests and their parasitoids is reviewed by Williams and Ferguson (Chapter 8 this volume).

2.5.3 Life Histories of Key Species

The biology of the key parasitoids of the cabbage stem flea beetle, the cabbage stem weevil and the rape stem weevil, namely *T. microgaster, T. obscurator* and *T. fulvipes*, respectively, have been studied extensively by Jourdheuil (1960). They are all univoltine, koinobiont, solitary endoparasitoids of the larvae and have similar life histories.

Adults overwinter in the fields where they have developed in their hosts on oilseed rape. According to the phenologies of the respective host larvae, they emerge from soil in early or late spring and migrate to the new oilseed rape crops in succession (Ferguson et al. 2006, Ulber and Nitzsche 2006). Further information on how weather parameters affect the emergence and migration of *T. microgaster* is presented by Johnen et al. (Chapter 15 this volume). Female parasitoids often show temporal synchrony with the vulnerable instars of their hosts in the crop. Crop location is aided by chemical cues emitted by infested host plants (see Williams and Cook, Chapter 7 this volume). The phenologies of emergence and the immigration of adult parasitoids into new oilseed crops was monitored by emergence traps, yellow water traps and Malaise traps in Germany and the UK (Ulber and Nitzsche 2006, Ferguson et al. 2006). Peak emergence of overwintering adult *T. microgaster* was observed in early March to April (Ulber and Wedemeyer 2004, Ferguson et al. 2006). Female parasitoids colonize new oilseed rape crops from March to May, indicating a high level of synchrony between immigration of parasitoids and the appearance of larval instars of the cabbage stem flea beetle within plants. First individuals of *T. obscurator* and *T. fulvipes* emerge in April and colonize new crops of oilseed rape simultaneously or a few days later, usually shortly before or at the beginning of flowering. Peak activity occurs in April/May when the crop is at full flowering and declines at the end of flowering (Jourdheuil 1960, Lehmann 1965, Nitzsche 1998, Ulber and Nitzsche 2006).

Female parasitoids forage on the rape plants, with antennation of the stem surface and ovipositor probing close to infested parts of the stem, suggesting that host microhabitat location and host recognition is assisted by contact chemosensory cues originating from the host plant or host (Ulber 2003). Females oviposit through the tissue of petioles or stems into host larvae while these are mining within the pith. After hatching, the parasitoid larva remains in its first instar within the host which apparently is not affected by parasitism (Jourdheuil 1960). However, after the mature host larva has migrated to the soil for pupation, the parasitoid larva develops rapidly and finally kills the host prepupa. The mature parasitoid larva spins a silken cocoon and pupates within the earthen cocoon prepared by the host. Adult parasitoids hatch in late summer and overwinter in diapause within the pupal cocoon in the soil. There is no information on alternative hosts for these *Tersilochus* species. Under laboratory conditions, the average longevity of newly-emerged females of *T. fulvipes* and *T. obscurator*, provided with rape flowers and water, was 53 and 58 days, respectively (Nitzsche 1998).

2.5.4 Percentage Parasitism

2.5.4.1 Cabbage Stem Flea Beetle

In all countries, the only parasitoid species found to attack the cabbage stem flea beetle during the MASTER project, with very few exceptions, was *T. microgaste*r. Assessments of parasitism by *T. microgaster* were conducted in four countries. The level of parasitism of larvae was variable (Fig. 2.11), ranging between 0 and 57% in Germany and Sweden, below 6% in two crops in Poland, and 11% in one crop in UK. In earlier studies from France and Germany, parasitisation rates of larvae by *T. tripartitus* (probably syn. with *T. microgaster* – see above) ranged from 30 to 61% and from 3 to 27%, respectively (Aubert and Jourdheuil 1958, Jourdheuil 1960, Dosse 1961). In Germany, in 2001, 2002 and 2003, at peak abundance of host larvae in the first decade of May, the field parasitism levels were 25% (n = 280), 44% (n = 792) and 23% (n = 127), respectively (Ulber and Wedemeyer 2004). There was no positive relationship between the abundance of host larvae per plant and the level of parasitism. While in 2000/2001 and 2001/2002 high numbers of host larvae were present within rape plants throughout the winter, in 2002/2003 the number of larvae started to increase only from the middle of March onwards. This might have affected the spatial-temporal coincidence between parasitoid and host populations resulting in different levels of parasitism.

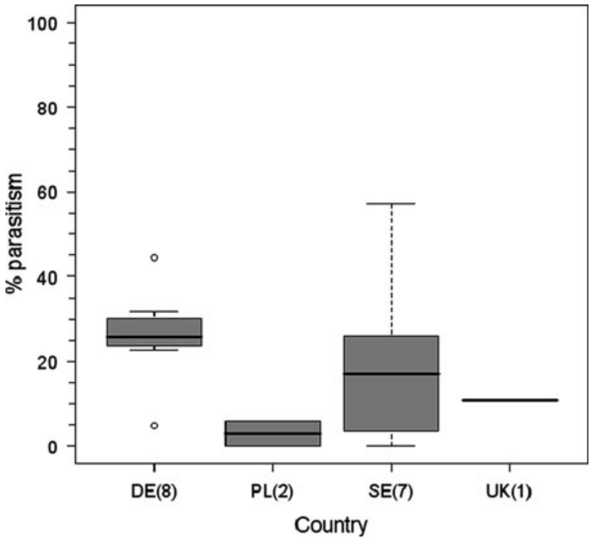

Fig. 2.11 Percentage larval parasitism of the cabbage stem flea beetle, *Psylliodes chrysocephala*, in crops of winter oilseed rape in Germany (DE), Poland (PL), Sweden (SE) and the UK in 1995–2005. In parentheses: number of oilseed rape crops examined

Superparasitism by *T. microgaster* occurs regularly, with up to nine encapsulated eggs and/or larvae of *T. microgaster* per individual host larva in 2002 in Germany (Ulber and Wedemeyer 2004). Superparasitism of parasitised larvae increased from 41 to 83% between 15 April and 22 May.

Parasitism levels by other species of parasitoid are negligible. *Aneuclis melanaria* parasitized only between 0.2 and 1.5% larvae in 1953, 1954, and 1955 in France (Jourdheuil 1960). In Germany, only 2–5% larvae were found parasitized by this species in the autumn of 1999, with no parasitism in the following years, despite high levels of larval infestation and extensive dissections and rearings of larvae (Ulber and Wedemeyer 2004). Parasitism by *Diospilus* spp. has also been reported to be low; this has been attributed to insufficient synchrony of the autumn generation of *D. morosus* and the host larvae (Jourdheuil 1960). In the studies conducted during the MASTER project from 2002 to 2005, no parasitism of cabbage stem flea beetle larvae by *Diospilus* spp. was found, even at higher host densities. *Trichomalus lucidus* (one female only) was reared from a total of 260 larvae sampled in May 2003 from a crop of oilseed rape at Goettingen/Germany (Ulber and Wedemeyer 2004), and two were reared from larvae in northern Germany (Nissen 1997).

2.5.4.2 Cabbage Stem Weevil

The parasitism of cabbage stem weevil larvae was determined from unsprayed crops of oilseed rape under various growing conditions in five European countries during the MASTER project (Ulber et al. 2006b). The level of parasitism ranged from 10 to 57%, with average levels in Germany, Poland and the UK at ca. 20% and in

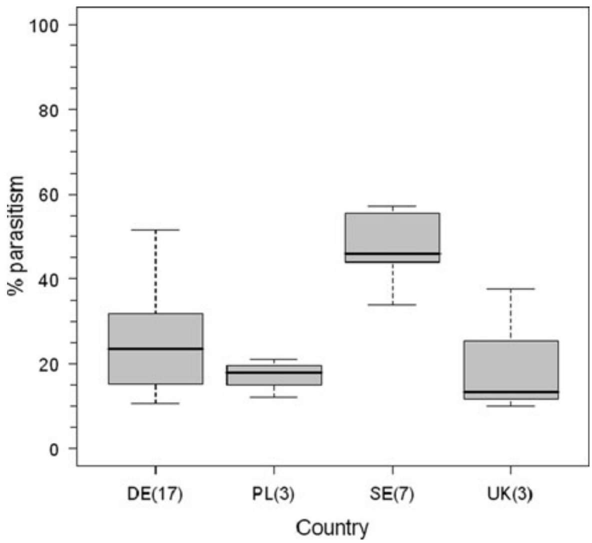

Fig. 2.12 Percentage larval parasitism of cabbage stem weevil, *Ceutorhynchus pallidactylus*, in crops of winter oilseed rape in Germany (DE), Poland (PL), Sweden (SE) and the UK in 1995–2005. In parentheses: number of oilseed rape crops examined

Sweden at ca. 50% (Fig. 2.12). With only very few exceptions, *T. obscurator* was the predominant parasitoid of the cabbage stem weevil.

As with the cabbage stem flea beetle, superparasitism of the cabbage stem weevil by *T. obscurator* was observed regularly in many crops of oilseed rape; for example in all crops sampled during 2003–2005 in the UK, with levels up to 39% of parasitized hosts (Williams unpublished). In Northern Germany, superparasitism was particularly evident at high levels of parasitism of host larvae, however, the level was not analysed in greater detail (Nissen 1997); encapsulation of parasitoid eggs and larvae within host larvae was also found.

2.5.4.3 Rape Stem Weevil

Levels of parasitism of the rape stem weevil determined in Germany and Poland during the project MASTER were considerably lower than those recorded in earlier studies from Austria, Czech Republic and France (Ulber 2003, Ulber et al. 2006b). In Germany and in Poland, parasitism in the majority of crops ranged between 2 and 14%, with a peak level of 21% in Germany (Fig. 2.13). *Tersilochus fulvipes* was the only parasitoid species identified from all samples. As the rape stem weevil is distributed only in Central Europe, there is no data on parasitism of this pest from the UK and Northern European countries.

Plant density affects plant architecture as well as microclimate and was found to affect percent parasitism of rape stem weevil larvae; it was higher in the lower sections of the main stems of plants when sowing densities were high (74 seeds/m^2) than when they were lower (25, 37 or 49 seeds/m^2) (Fischer and Ulber 2006). Presumably the thinner stems of high density plantings allow greater access of

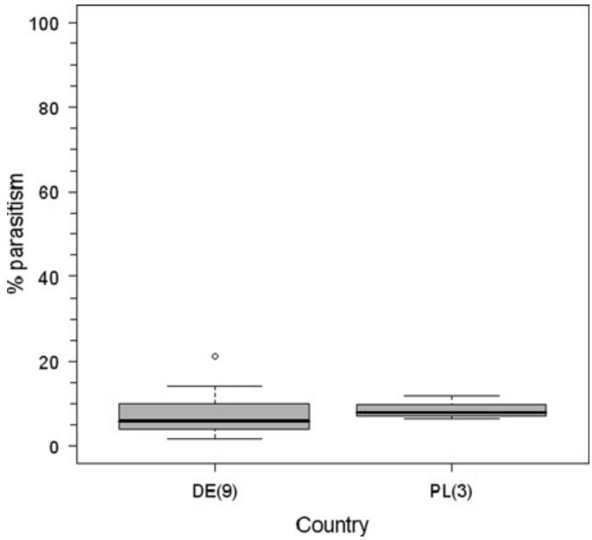

Fig. 2.13 Percentage larval parasitism of rape stem weevil, *Ceutorhynchus napi*, in crops of winter oilseed rape in Germany (DE) and Poland (PL) in 1995–2005. In parentheses: number of oilseed rape crops examined

parasitoids to their host larvae within the stems. However, at very low plant density (10 plants/m^2), a greater proportion of host larvae was parasitized within lateral branches and the level of parasitism was higher than at high plant density (70 plants/m^2) (Neumann and Ulber 2006). As the ovipositor length of *T. fulvipes* females is only 4.2 mm, thick stems can provide structural refuges for rape stem weevil larvae (Ulber 2003). Further, the species and cultivars of the *Brassica* host plant have significant effects on larval parasitism of rape stem weevil (Ulber et al. 2006a).

2.6 Conclusions and Implications for Biocontrol-Based IPM in Oilseed Rape

At least 80 species of hymenopteran species are known to parasitise the six economically most important pests of oilseed rape but only 12 of these were identified by the EU-funded project MASTER as sufficiently widespread and abundant across Europe to be of potential economic importance for biocontrol of these six pests. Most of the 12 parasitoid species were recorded from all five project partner countries where their host species is present.

The emergence and seasonal activity periods of the key parasitoids within crops of oilseed rape are closely synchronized with the phenologies of the pre-imaginal life stages of the target host populations. Immigration of parasitoids usually starts shortly after the beginning of host oviposition or hatching of host larvae on plants.

In most European countries, the level of parasitism of target pests is high, frequently ranging between 10 and 50%, with parasitism of cabbage seed weevil and pollen beetle in Sweden, Germany and the UK occasionally exceeding 70 and 90%, respectively. However, the level of parasitism of the six most damaging pests of oilseed rape varies between years and countries, and in some seasons the abundance of pest populations is too low for reliable estimations of percentage parasitism. Percentage parasitism of target pests frequently exceeds the threshold of 30% below which biological control has rarely been found to be successful (Hawkins and Cornell 1994). The most important consequence of parasitism is direct or later mortality of pest larvae, leading to reductions in adult pest populations for the following year. Thus, the results obtained during the MASTER project provide further evidence that the key parasitoids have potential to significantly reduce pest populations, in many years keeping pest densities below thresholds of economic damage, thereby exerting an important role for the natural regulation of pests.

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