Hover flies (Diptera: Syrphidae):

Trap efficiency, phenology and pollen feeding.

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Hover flies (Diptera: Syrphidae):

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A dissertation

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of the requirements for the degree

of

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by

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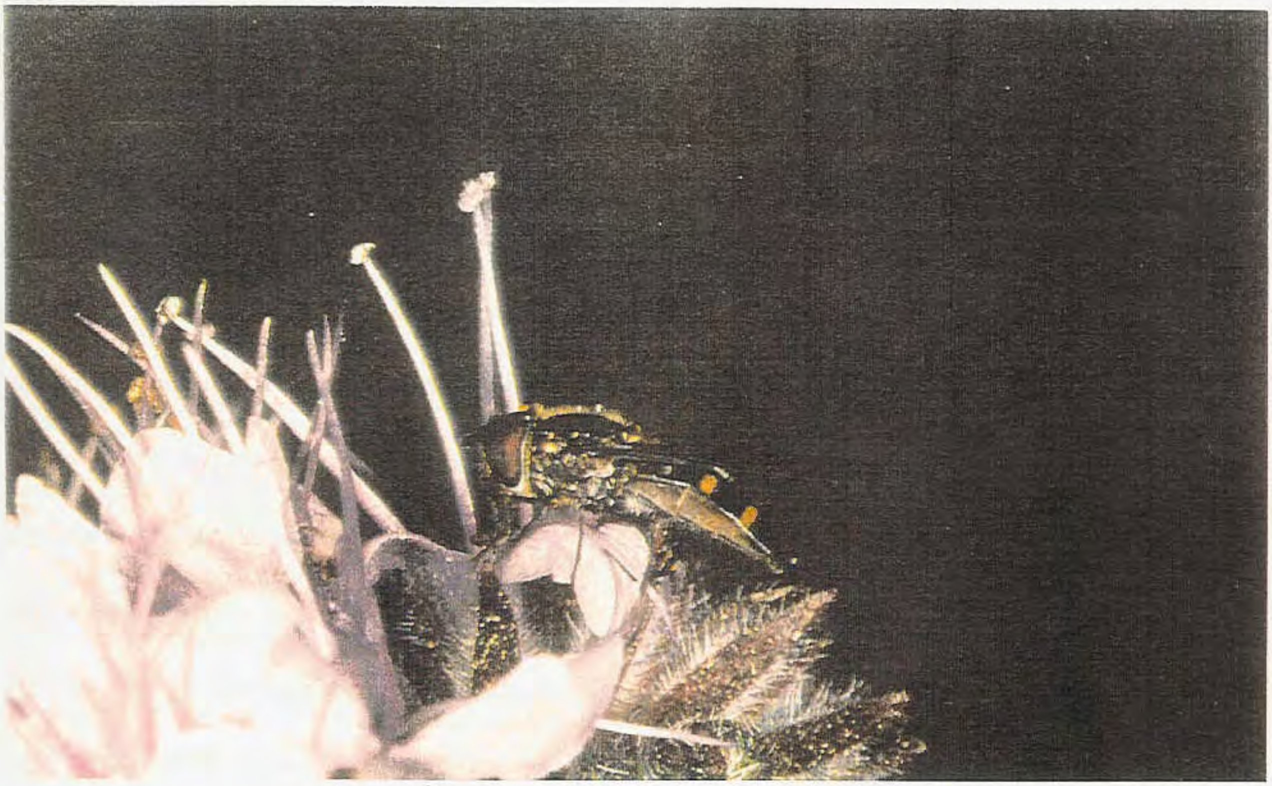

Plate 1. Frontispiece *Melangyna novaezelandiae* adult on *Phacelia tanacetifolia* flowers.

Abstract

Hoverflies show potential as biological control agents of aphid populations; however, additional information is required on the ecology and phenology of New Zealand hoverflies to minimise their contribution to biological control. The adult flies use nectar for energy and pollen for egg maturation, so an increase in floral diversity may enhance hoverfly numbers and, in turn, aphid predation.

The phenology of the two aphidophagous hover fly species, *Melanostoma fasciatum* (Macquart) and *Melangyna novaezelandiae* (Macquart) as well as that of the non-aphidophagous species *Eristalis tenax* L. were monitored over a two year period. The primary objective was to determine whether higher amounts of pollen in the immediate environment increased the number of hover flies, the proportion of gravid females and the proportion of hoverflies with guts with high amounts of pollen. A secondary objective was to investigate the effect of trap colour (yellow-sided traps versus green-sided traps) on the populations of hover flies caught.

Numbers of *M. fasciatum* captured reached a peak in late December-January. There was a peak of female *E. tenax* in early August to mid-September whereas male *E. tenax* reached a peak in early January. Catches of female *M.novaezealandiae* reached a peak in mid-January, 1995 and in mid-March, 1996. In comparison, male *M.novaezealandiae* numbers reached a peak in late December, 1994 and remained relatively low during 1995-1996.

There was a significantly higher number of male *M. fasciatum* caught at the horticultural site compared with the arable and phenology sites. There was significantly more male *M. novaezelandiae* at the phenology site compared with the arable and horticultural sites. There

were significantly more female *M. novaezelandiae* at the phenology site compared with the horticultural and arable sites.

Gut fullness and the number of eggs in *M. novaezelandiae* and *M. fasciatum* were at their lowest from June to September, 1995. In contrast, gut fullness and the number of eggs in *E. tenax* were at their highest from June to September, 1995.

M. novaezelandiae had a significantly higher gut fullness than did *M. fasciatum,* and for all species combined, gut fullness was significantly higher in gravid females compared with non-gravid and male hover flies.

Gut fullness in *E. tenax* was significantly higher in phenology and horticultural sites compared with the arable site. There was no significant effect of species or gut fullness on the mean number of eggs per female for each species. The mean number of eggs per female *E. tenax* was significantly higher at the horticultural and phenology site compared to the arable site.

There was no significant difference between the number of different pollen types consumed in summer, autumn, winter and spring for all sexes of *E. tenax.* Gravid *M. fasciatum* consumed a significantly higher number of pollen types in summer compared with autumn. The number of different pollen types consumed by *M. novaezelandiae* was lower in winter compared with all other seasons for all genders. There was a significantly larger number of pollen types consumed by gravid *M. novaezelandiae* in autumn compared with spring and summer. *M. novaezelandiae* consumed 23 different pollen types throughout summer, 28 in autumn, 4 in winter and 17 in spring. Males of *M. novaezelandiae* consumed a higher number of different pollen types in spring compared with females which consumed a higher number of different pollen types in summer and autumn. *M. fasciatum* consumed fewer different pollen types in summer and autumn than *M. novaezelandiae* and *E. tenax. E. tenax* consumed

15 species all year round, with male flies consuming a wider range of pollen types in summer and autumn and female flies consuming a wider range of pollen types in winter and spring. This is an opposite trend to that of *M. novaezelandiae*. *E. tenax* consumed a higher number of different pollen types in winter compared with *M. novaezelandiae*, these included *Salix* sp., *Erica* sp. and *Pinus* sp., probably accounting for the higher degree of gut fullness obtained in winter for *E. tenax*

Poaceae, Asteraceae, *Brassica* type and Caryophyllaceae were used all year by *M. novaezelandiae*. *M. novaezelandiae* was the only species to feed on *Geranium* sp., *Ribes* sp. and *Centaurea* sp, whereas *M. fasciatum* was the only species not to feed on *Pinus* sp. Gravid female *M. fasciatum* were the only flies to feed on *Rumex* sp., and *E. tenax* did not consume *Phacelia.*

Gravid *E. tenax* and male *M. novaezelandiae* consumed a significantly higher number of different pollen types in the horticultural site compared with the arable site. This same trend was consistent for gravid and non-gravid females of all species. In contrast, male *E. tenax* and *M. fasciatum* consumed a significantly lower number of different pollen types in the arable site compared with the horticultural site.

Results from this experiment also showed that by increasing floral diversity in the immediate environment, the abundance of hoverflies can be enhanced, gut fullness can be increased and the number of eggs in female hoverflies can be increased.

The value of the work in providing background ecological information for possible enhancement programmes for hover fly populations in crops is discussed.

Key words: Hover flies, Syrphidae, trap efficiency, gut fullness, phenology, New Zealand.

TABLE OF CONTENTS

Page

Chapter

1. Literature review

2. Methods

3. Results

4. Discussion

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Chapter 1.

Literature review

The aims of this literature review are:

1. To outline the advantages of biological control as a means of controlling aphid populations.
2. To provide a brief overview of the biology of hover flies.
3. To give an account of the mechanisms behind habitat manipulation to enhance hover fly numbers and predation rate.
4. To evaluate previous research work that has pointed to the potential of using hover flies for biological control of aphid populations.

1.1 The need for biological control

Aphids are one of the world's most economically important pests, infesting a large range of plants, including horticultural crops, forest trees, ornamentals and field crops. They are one of the most widespread groups of pests in agricultural systems and include many species in a wide range of genera. For example, in the Çukurova region of Turkey, during 1979-1981, there were 18 species of aphids in 11 genera reported damaging vegetable crops alone (Orman & Bakanligi, 1989).

Aphids cause large economic losses around the world. For example, Wang, Fang, Zheng, Lin, Shang and Wang (1994) reported soybean yield losses from aphid infestations in China of up to 51.8% and Mandal, Misha and Patra (1994) reported rapeseed and mustard yield losses from aphid damage in India of up to 83.3%. Control of over-wintering aphid populations in

New Zealand increased spring yields of lucerne (*Medicago sativa* (L.)) by 35% (White & Lucas, 1990).

Aphids cause direct injury to crops through injection of active substances in saliva which interferes with crop physiology, and by the removal of amino acids and carbohydrates from the phloem sap of the plant. Aphids can cause indirect injury to crops by virus transmission, honey-dew excretion and changes in the microflora communities on plant surfaces which may influence the physiological performance of the plants (Blackman, 1974; Wellings, Ward, Dixon and Rabbinge, 1988).

Hence, when aphid numbers are above the economic threshold, it is necessary to reduce their numbers. Current control methods for aphids include: resistant cultivars, and various forms of cultural, biological, and chemical control. However, the predominant form of control is chemical and there are many potential adverse effects of this. For example, chemicals can be persistent and build up in the environment, including in the soil and aquifers. They can leave residues on produce, therefore decreasing overseas market access, and they can be detrimental to human health (Sridhar, 1989; Mel' nikov and Kozhevnikova, 1991).

Many broad-spectrum insecticides are harmful to 'non-target organisms', including natural enemies (Çilgi, Wratten, Robertson, Turner, Holland & Frampton, 1996), sometimes resulting in secondary pest outbreaks and pest resurgence. For example, the aphicide demeton-S-methyl causes changes to liver cells and certain blood and brain enzymes in rabbits (*Oryctolagus cuniculus* (L.)) (Tarrant, Thompson and Greig-Smith, 1992) and reduces blood enzyme activity in house sparrows (*Passer domesticus* (L.)) and changes their natural foraging habits and diets (Hart, Thompson, Fletcher, Greig-Smith, Hardy and Langton, 1992). Yumruktepe & Uygun (1994) showed that the aphicide furanthiocarb was highly toxic to larvae and adults of the two predatory ladybird species *Cryptolaemus montrouzieri* (Mulsant) and *Nephus includens* (Kirsch) .

Extensive use of insecticides has led to the development of resistance in aphid populations, which represents one of the major threats to the future success of chemical pest control. For example, certain *Rhopalosiphum padi* (L.) populations in the USSR showed a 30-fold resistance to organophosphate insecticides and a 25-fold resistance to pyrethroids (Sekun, Kudel', Satsyuk, Mel'nikova, Zil'bermints and Zhuravleva, 1990), and resistance to insecticides by *Myzus persicae* (Sulzer) has made cultivation of chillies uneconomical (Kandasamy, Mohanasundaram and Karuppuchamy, 1989).

Hansen (1994) concluded that the only way to reduce the incidence of resistance of aphid populations is to reduce the frequency of spraying. Therefore, with the build up of aphid resistance to chemical control and the many other detrimental effects of chemical usage, the need for an alternative control method is apparent.

1.2 Biology of hover flies

There are more than 4700 species of hover fly (Diptera: Syrphidae) worldwide, with about 300 in central Europe (Chambers, 1988). Aphidophagous hover flies are characterised by an extremely active adult insect whose abdomen is often brightly coloured with bands or patches, of yellow or white, on a black or brown background. They have an aptitude for hovering flight and are distinguishable from almost all other Diptera by the presence of a 'false vein' ('*vena spuria*') in the wing (Coe, 1953).

Most aphidophagous species are found in two tribes of the family Syrphidae: Syrphini and Melanostomi. The Syrphini includes *Metasyprhus corollae* (Fabricus) and *Episyrphus balteatus* (de Greer), of which the former species is probably the most intensively researched among the Syrphidae (Chambers, 1988). The common European species among the Melanostomi are *Platycheirus peltatus* (Meigen), *P. manicatus* (Meigen) and *Melanostomus scalare* (Fabricus).

In New Zealand two native hover fly species, *Melanostoma fasciatum* (Macquart) and *Melangyna novaezelandiae* (Macquart), have aphidophagous larvae and are commonly found in the agricultural environment (Lovei, McDougall, Bramley, Hodgson and Wratten, 1992). Both are abundant throughout the country, although, *M. fasciatum* is more common, especially in the North Island (Miller, 1921). Not only do these hover fly larvae feed on aphids (Rohitha, Pottinger and Firth, 1985) but they also predate early-instar lepidopteran larvae, e.g., white butterfly, *Artogeia rapae* (L.) and diamondback moth, *Plutella xylostella* (L.) (Valentine, 1967; Miller, 1971; Ashby & Pottinger, 1974).

Adult hover flies can be observed on the wing mainly from spring to autumn and visit flowers to feed on pollen and nectar (Holloway, 1976; Miller 1918). Pollen provides protein which is required for sexual maturation of female eggs while nectar (or aphid honeydew) provides energy and aids digestion (Schneider, 1948). Adult aphidophagous hover flies lay their eggs singly or sometimes in pairs close to, or among aphid or caterpillar colonies. The eggs are generally elongated ovoid with one end narrower than the other. However, size varies between species, with the larger species generally laying larger eggs (Gilbert, 1986). Development of syrphid eggs is rapid in aphidophagous species. For example, those of *E. balteatus* develop within 4.8 days at 15°C (Ankersmit, Dijman, Keuning, Mertens, Sins & Tacoma, 1986) and those of *M. corollae* within 2.7 days at 21°C (Chambers, 1986). Hover fly larvae are legless and are wider towards the posterior end and tapered to a point at the anterior end (Miller, 1918). There are three larval instars in all syrphid species and development is retarded during the winter when the final instar may last several months

(Benestad, 1970). The larvae feed by piercing a hole in their prey using their mouth hooks and holding it above the plant surface while extracting the liquid body-contents.

1.3 Habitat manipulation

Habitat manipulation is the conservation or enhancement of populations of indigenous natural enemies by manipulating the environment to enhance their activity against a particular pest or pest complex.

The current trend in agriculture is towards extensive monocultures: a single species in large a area, which has, in turn, removed the diversity from stable natural systems. MacArthur (1955) investigated the information flow through links in the food web and concluded that "(1) Stability increases as the number of links increase, (2) If the number of prey species for each species remains constant, an increase in numbers of species in the community will increase the stability, (3) A given stability can be achieved either by large numbers of species each with fairly restricted diets, or by a smaller number of species each eating a wide range of other species." Recent reviews carried out to test the idea that an increase in diversification of agroecosystems may increase their stability show that careful diversification of the vegetational components of agricultural habitats often lowers pest populations (Risch, Andow & Altieri, 1983; Wratten & Emden, 1985; Russell, 1989). Root (1973) proposed two possible hypotheses for this observation. These were:

1. The resource concentration hypothesis

Herbivores less easily find, stay in and reproduce in diverse systems due to:

- disruption of chemical and visual cues
- restricted movement within the crop

- an increase in emigration from the crop

2. <u>The natural enemies hypothesis</u>

Predator and parasite numbers are enhanced due to:

- providing alternative hosts/prey at times of scarcity
- providing food (pollen and nectar) for adult parasitoids and predators
- providing refuges for over-wintering

The importance of pollen and nectar in the life cycles of many natural enemies is well established (Thorpe & Caudle, 1938; Zandstra & Motooka, 1978). Adult hover flies require nectar for energy, and pollen for gametogenesis (Schneider, 1948; Chambers, 1988); therefore the establishment of flowering plants in the vicinity of crops has been suggested as a way of increasing the abundance of hover fly larvae, in turn enhancing the potential for syrphids to have a major influence on the regulation of aphid populations. This is of direct relevance to this investigation and will be discussed in Section 1.4.3.

1.4 The potential of using hover flies as biocontrol agents

1.4.1 Egg laying and predator rate potential

Hover flies show potential as biocontrol agents because their adult stage is mobile and active and many species actively seek out and oviposit among the larval food. This may enable them to have potential in a cropping situation which involves rotation of annual crops, because they are able to migrate extensively to seek out the target aphids (Hughes, 1988).

Syrphid larvae are predators and therefore consume many aphids during their development; consequently they are potentially more beneficial then parasitic biocontrol agents because it means that their body size is not limited to that of their prey. They also may be more suited to reduce the very dense colonies characteristic of some aphid species, such as *Aphis gossypii* (Glover) than are aphid parasites (Ramakers, 1988)

Potential prey do not appear to react to the presence of syrphid eggs laid among aphid colonies (Chambers, 1988) which is essential for the success of hover flies as biological control agents. Otherwise, the aphids may avoid hover fly-egg-infested leaves or move away from any larvae present. The number of eggs laid in response to aphid density is also an important feature in determining the potential of hover flies as a means of aphid control, because as the aphid density increases, a higher number of hover fly larvae will be required to control the aphid's reproduction. At higher aphid densities, an increasing number of syrphid eggs are laid (Chandler, 1968a; Sanders, 1979; Ito a& Iwao, 1977). However, this occurs only up to a maximum density of aphids, above which oviposition is deterred, and some hover fly species, for example, *P. peltatus*, do not show a density-related oviposition response (Chandler, 1968a).

Aphids have an extremely large reproductive potential, therefore, if hover flies are to successfully control aphid populations, they must arrive early and have a high reproduction and predation rate. Benestad (1970) showed that a female *M. corollae* lays an average of 436 eggs in her lifetime in laboratory conditions. However, not all these eggs are fertile. It is somewhat difficult to determine the effects of predation on an aphid population as there are no corpses remaining to be counted. However, *E. balteatus* larvae consumed an average of 416 *Aphis pomi* (de Geer) during their development (Wunk, 1977) and 550 *Brevicoryne brassicae* (Linnaeus) (Wunk and Fuchs, 1977). Smaller hover fly species, such as those of the Melanostomini, consume fewer aphids; for example, *Melanstoma mellinum* (Linnaeus) consumed 150 aphids in total (Bankowska, Mikolajczyk, Palmowsk and Trojan, 1978).

Therefore, the larger species of Syrphidae may be more efficient at regulating hover fly numbers. So the question remains, under what circumstances, if any, are the reproduction and predation of hover flies high enough for them to be an efficient biological control agent of aphids?

1.4.2 Effectiveness of hover flies as biocontrol agents

The effectiveness of hover flies in reducing aphid populations is difficult to assess because of the presence of other natural enemies, such as coccinellids; however, several European studies show that the presence of syrphid larvae may prevent aphid population increases (Chambers & Sunderland, 1983; Chambers, Sunderland, Stacey and Wyratt, 1986; Hickman & Wratten, 1994). For example, Chambers & Adams (1986) found that syrphid larvae had the potential to halt cereal aphid population growth in field trials of winter wheat and Sengonça & Frings (1988) showed that the presence of syrphid larvae can actually cause a decline in aphid numbers. In contrast, Harwood, Hickman, MacLeod, Sherratt and Wratten (1994) concluded that the evidence that greater densities of adult syrphids promote significant control of aphid populations is questionable. Poor control can arise from the late appearance of gravid females or low fly density (Chambers, 1988).

1.4.3 Enhancing hover fly numbers by habitat manipulation

New Zealand studies show that *Phacelia tanacetifolia* Benth. is attractive to the native hover fly species (Lovei, Hodgson, MacLeod and Wratten, 1993) and when planted in strips across fields, can increase local hover fly densities (Lovei *et al.*, 1992). In fact, White, Wratten, Berry and Weigmann (1995) demonstrated that border planting *Phacelia* around cabbage crops significantly increased hover fly populations and decreased the numbers of aphids. In contrast, Chandler (1968b) did not find any increase in the number of syrphid eggs laid after flowers were placed in plots of Brussels sprouts infested with aphids. This could be due to the considerable mobility of the adult stages which would mean that adult feeding could take place far from oviposition sites (Pollard, 1971).

Studies show that weed density or the density of non-crop plants, has a significant impact on the abundance of Syrphidae among the crop. For example, Cowgill, Wratten and Sotherton (1993) found a significant positive relationship between the number of syrphid eggs present and weed density, and Harwood, Wratten and Nowakawski (1992) showed that the establishment of wild-flower strips around field margins increased hover fly activity within the adjacent crop.

To retain hover flies in the field, Hagen, Sowall and Tassan (1970) used a sucrose spray with a commercial yeast product as food for natural enemies when prey density was low; however, in the absence of aphids, no oviposition occurred.

1.4.4 Additional benefits

Not only do hover flies have the potential to stop aphid population growth and to decrease aphid numbers, but there are additional benefits to using them as biocontrol agents. Both sexes of syrphids visit flowers to ingest pollen and nectar which is required for gametogenesis (Chambers, 1988) and in doing so they also contribute to the pollination of these flowering plants. For example, Abrol (1989) observed that hover flies seem to be efficient pollinators of umbelliferous crops.

1.4.5 Problems and limitations

A problem with using hover flies as biological control agents is that they can be parasitised and predated, which may in turn influence their feeding behaviour or abundance. Chambers (1988) reported that nine families of hymenopterous parasitoids attack syrphids.

A disadvantage of using syrphids as a biocontrol agent compared with other predators is that only the larval stages of hover flies predate on aphids, whereas both the adult and larvae of most coccinellid species feed on aphids. This in turn delays the impact that hover flies have on the aphid populations.

In comparison with chemical control, biological control using hover flies is dependent on environmental conditions, and if they are not favourable they may influence their growth, development, fecundity, abundance and predation rate, and hence the impact on controlling the aphid population. The adults are active fliers and therefore may leave the crop when aphid densities are low or when the conditions are unfavourable, in turn not implementing control of the aphid population.

Some aphid species may not be able to be controlled by syrphids as they are unsuitable as food. For example, *M. corollae* can not complete development on *Cavariella theobaldi* (Gillette Bragg), and *Aphis sambuci* (Linnaeus) is toxic to the larvae (Ruzicka, 1975).

Hover flies are selective predators that feed on aphids and some lepidopteran larvae, therefore if other pests are present in the crop, then a combination of control methods would have to be adopted to control all of the pests present. In contrast, one application of a broad-spectrum insecticide may control them all, at least in the short term.

Hover flies may have a role in integrated control of aphid populations, where many different forms of cultural, biological and chemical control are implemented. However, there are problems associated with using hover flies in integrated control which suggests that other predators may be more suitable. Currently there is no insecticide which is selective enough to kill aphids but preserve syrphids. For example, Hassan, Bigler, Bogenschutz, Brown, Firth, Huang, Ledieu, Naton, Oomen, Overmeer, Rieckman, Samsoe-Petersen, Ledieu,Van Zon (1983) reported that all of the commercial insecticides available for controlling aphids killed in excess of 80% of *Syrphus vitripennis* (Meigen) larvae. Insecticides not only cause injury by directly killing hover flies (Vickerman & Sunderland, 1977) but they also cause indirect effects such as secondary poisoning caused by consumption of insecticide-contaminated prey, latent mortality, and reductions in survivorship, longevity, rate of development, fecundity and other components of fitness (Horn & Wadleigh, 1988). Even pirimicarb, which is a relatively non-toxic chemical which does not affect other natural enemies of aphids (Çilgi, Holland, Turner, Frampton, Wratten and Jepson, 1994; Yumruktepe & Uygun, 1994; Schoemans, 1995), is harmful to hover flies (Proctor & Baranyovits, 1969).

1.4.6 Previous research and additional information required

The many reports of a correlation between the number of syrphid larvae present and the prevention of aphid population increases indicates that, at least in some field situations, hover flies show potential for the biological control of aphid populations. This impact on aphid populations may be attributed to 1) the good mobility and searching ability of the adults, 2) the habit of some species of hover fly of depositing eggs among the larval food, and 3) the rapid rise in the predation rate as the larvae grow (Chambers, 1988).

However, it is important to understand the phenology and ecology of the insects involved, to ensure successful biological control, but for hover flies in New Zealand this information is still limited. For example, Wratten, White, Bowie, Berry and Weigmann (1995) based studies of phenology and pollen preference of *M. fasciatum* and *M. novaezelandiae* on a 55-day period and concluded that there was a second generation occurring in late summer. It was also found that *Taraxacum*-type pollen was the most frequently occurring pollen in the guts of both species of New Zealand hover flies in the horticultural and arable habitats in the study. Hickman, Lovei and Wratten (1995) based their study on a 36-day period and concluded that plantain (*Plantago* sp.), *Phacelia*, coriander (*Coriandrum sativum* (L.)) and Gramineae (Poaceae) pollen was consumed in large quantities by gravid *M. fasciatum* females and that there were differences in pollen preference between the sexes. Because both these studies occurred over short periods it raises the question of whether pollen preference changes with the seasons.

A study in the UK involving Conservation Headland (Sotherton, 1991) techniques showed that by modifying herbicide regimes in the headlands of cereal fields, weed densities increased which in turn increased the number of syrphid eggs laid (Cowgill *et al.* 1993). This technique has advantages for biological control and additional benefits for the conservation of wildlife (Rands, 1985). However, this technique has not yet been evaluated in New Zealand.

The efficiency of traps to catch hover flies is also virtually unstudied in New Zealand. Wratten *et al.* (1995) conducted an experiment to determine trap colour attractiveness and found that yellow was the most attractive colour for *M. novaezelandiae*; however, for *M. fasciatum*, yellow, white and blue traps caught equivalent numbers and green was the least attractive. Yellow traps are frequently used to trap adult hover flies (Lovei *et al.* 1992; Harwood, Hickman, MacLeod, Sherratt & Wratten, 1994; White *et al.* 1995). However, a study in the UK showed that using yellow traps which are conspicuous and easily seen will draw in a population of hover flies which have a less pollen in their gut than populations caught in traps which are less conspicuous (Hickman, Wratten & Jepson, 1997). They also found that a smaller proportion of flies was caught when flowers are present and competing with the crop than when flowers are not present.

However, trap efficiency and the effect of trap type still needs to be investigated in New Zealand hover fly species.

Although detailed studies have been carried out on hover flies overseas, and limited studies on hover-fly phenology have been carried out in New Zealand, more information is required on hover-fly phenology throughout the season, together with the use of increased floral diversity such as border planting (e.g., White *et al.* 1995) and Conservation Headland techniques (e.g., Sotherton, 1991) etc. in New Zealand. Fundamental to all these situations is the need to understand trap efficiency.

1.5 Aims of the investigation

The following investigation researches the phenology of the two aphidophagous hover fly species *M. novaezelandiae* and *M. fasciatum*, as well as the non-aphidophagous species *Eristalis tenax* L., as data on this species is still useful in understanding the biology of flower-feeding hover flies. It also compares hover fly populations between a florally diverse site and an arable site, and between green-sided yellow traps and yellow-sided yellow traps. The aims of the investigation are to address the following questions:

- Do higher amounts of pollen in the immediate environment increase the proportion of gravid females and of flies with full guts?
- What are the changes in pollen 'preference' throughout the year?
- Does pollen 'preference' and gut fullness differ between species of hover fly, and between sexes and gravid and non-gravid females, throughout the year?

- What are the proportions of hover fly species, sexes and gravid/non-gravid females throughout the year?
- Do yellow-sided yellow traps capture a different population than do green-sided yellow traps with respect to:

* ratio of species

* sex ratios

* gravid to non-gravid females

* pollen contents - types of pollen

- gut fullness

- Do the yellow-sided water traps trap more hover flies overall than do the green-sided traps

1.6 Outputs and outcomes

Outputs

- Dissertation submitted as partial fulfilment of the requirements for the degree of Bachelor of Horticultural Science with honours.
- Manuscript to be published in a journal
- Presentation of results as part of a departmental seminar

Outcomes

- Improved protocols for hover fly population assessment
- Better understanding of the role of plant ecological diversity on hover fly ecology and biocontrol

Chapter 2.

Methods

2.1 Comparing arable and more florally diverse sites

2.1.1 Site description

Adult hover flies were collected using yellow water traps at two sites in Lincoln University, Canterbury during 1996. The first site was on the Lincoln University Cropping Farm in arable land and pasture. Fifteen yellow (trap reflectance 500nm) plastic two-litre containers (170 x 170 x 85 cm) with sides painted green, were placed on the ground in three replicates of 5 traps each (30-40 metres apart) using fences as boundaries to divide the replicates. Individual traps within a replicate were positioned 10 metres apart (Fig. 2.1).

The second site was at the Biological Husbandry Unit within the Lincoln University Horticultural Research Area in which fifteen traps as above were placed in three replicates of 5 traps each (20-40 meters apart) using paths and shelter belts as boundaries. Individual traps within a replicate were positioned 10 metres apart (Fig 2.2). Refer to Tables 2.1 and 2.2 for the species of plants that were present at the horticultural and arable sites respectively.

2.1.2 Experimental procedure

Each trap was three-quarters filled with water to which a few drops of detergent were added together with approximately 5 g of sodium benzoate as a preservative.

Trap catches were first assessed on March 19 and subsequently at approximately weekly intervals until the July 25. This involved carefully decanting some of the liquid from the trap and the hover flies and any insects which were similar and of uncertain identity were removed

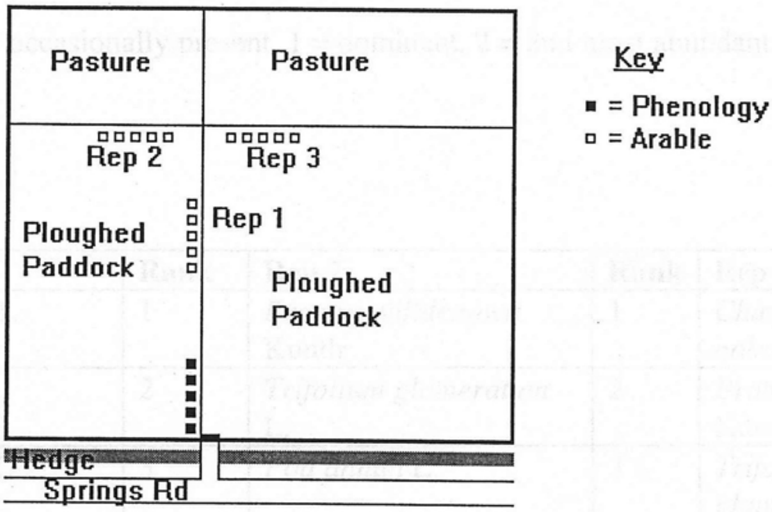

Fig. 2.1 Trap and replicate layout at arable and phenology sites located on the Lincoln University Cropping Farm, Springs Rd.

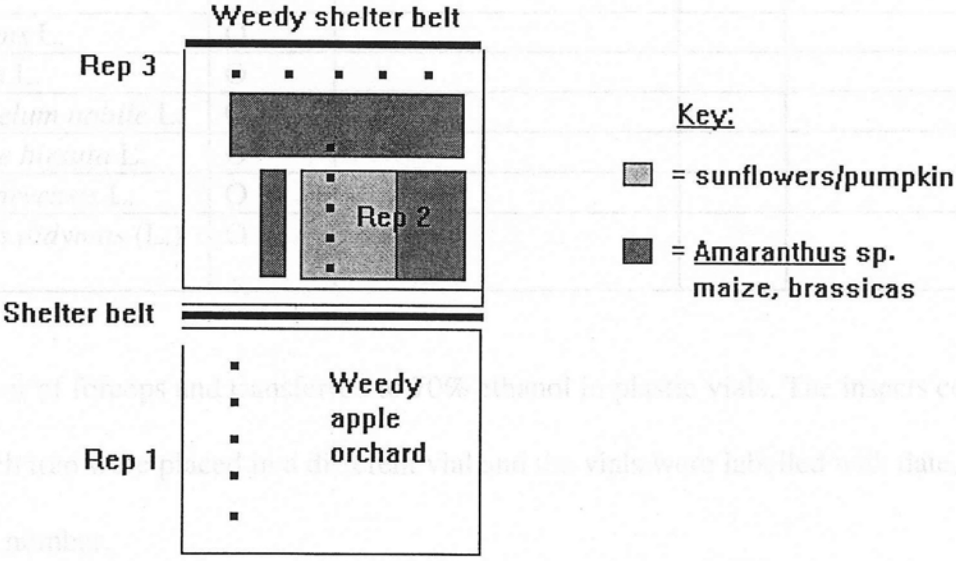

Fig 2.2 Trap and replicate layout for horticultural site located at the Lincoln University Horticultural Research Area, Farm Rd, Lincoln University.

Table 2.1 Ranking of the relative abundance of plant species which were present at the arable site, O = occasionally present, 1 = dominant, 2 = 2nd most abundant, 3 = 3rd most abundant).

Rep 1	**Rank**	**Rep 2**	**Rank**	**Rep 3**	**Rank**
Malva sylvestris L.	1	*Bromus willdenowii* Kunth	1	*Chamaemelum nobile* L.	1
Veronica sp.	2	*Trifolium glomeratum* L.	2	*Bromus willdenowii* Kunth	2
Galium aparine L.	3	*Poa annua* L.	3	*Trifolium glomeratum* L.	3
Capsella bursa-pastoris (L.) Medic.	4	*Chamaemelum nobile* L.	4	*Taraxacum officinale* Weber	O
Senecio vulgaris L.	O	*Taraxacum officinale* Weber	O	*Veronica* sp.	O
Fumaria muralis Sond. ex Koch	O	*Capsella bursa-pastoris* (L.) Medic.	O	*Poa annua* L.	O
Viola arvensis Murr.	O	*Bromus* sp.	O	*Rumex obtusifolius* L.	O
Sonchus oleraceus L.	O				
Erodium moschatum (L.) L'Herit	O				
Urtica urens L.	O				
Poa annua L.	O				
Chamaemelum nobile L.	O				
Cardamine hirsuta L.	O				
Veronica arvensis L.	O				
Coronopus didymus (L.) Sm.	O				

with a pair of forceps and transferred to 70% ethanol in plastic vials. The insects collected from each trap were placed in a different vial and the vials were labelled with date, replicate, and trap number.

In the laboratory adult *M.novaezealandiae, M. fasciatum* and *E. tenax* were identified and sexed (eyes touching dorsally in males; eyes not touching in females) using a dissecting microscope x 10.

Table 2.2 Ranking of the relative abundance of plant species which were present at the horticultural site (O = occasionally present, 1 = most dominant, 2 = 2nd most abundant, 3 = 3rd most abundant).

Rep.1	**Rank**	**Rep.2**	**Rank**	**Rep.3**	**Rank**
Dactylis glomerata L.	1	*Poa annua* L.	1	*Poa annua* L.	1
Anthriscus sylvestris (L.) Hoffm.	2	*Lolium perenne* L.	2	*Lolium perenne* L.	2
Rumex obtusifolius L.	3	*Bromus willdenowii* Kunth	2	*Bromus willdenowii* Kunth	2
Cirsium arvense (L.) Scop.	O	*Trifolium glomeratum* L.	3	*Trifolium glomeratum* L.	3
Taraxacum officinale Weber	O	*Taraxacum officinale* Weber	4	*Taraxacum officinale* Weber	4
Pastinaca sativa L.	O	*Rumex obtusifolius* L.	O	*Rumex obtusifolius* L.	O
Galium aparine L.	O	*Galium aparine* L.	O	*Galium aparine* L.	O
Bromus willdenowii Kunth	O	*Lamium purpureum* L.	O	*Lamium purpureum* L.	O
Lolium perenne L.	O	*Veronica* sp.	O	*Veronica* sp.	O
Ranunculus sp.	O	*Capsella bursa-pastoris* (L.) Medic.	O	*Capsella bursa-pastoris* (L.) Medic.	O
Lamium purpureum L.	O	*Myosotis laxa* (Schultz) Nordh.	O	*Myosotis laxa* (Schultz) Nordh.	O
Asparagus sp.	O	*Anthriscus sylvestris* (L.) Hoffm.	O	*Anthriscus sylvestris* (L.) Hoffm.	O
Symphytum officinale L.	O	*Erodium moschatum* (L.) L'Herit	O	*Erodium moschatum* (L.) L'Herit	O
Euphorbia peplus L.	O	*Quercus* sp.	O	*Rubus fruticosus* agg.	O
Rubus idaeus L.	O	*Lupinus arboreus* Sims	O	*Salix* sp.	O
Quercus sp.	O	*Salix* sp.	O	*Sonchus oleraceus* L.	O
Lupinus arboreus Sims	O	*Cotoneaster* sp.	O	*Zea mays* L.	O
Salix sp.	O	*Prunus* sp.	O	*Phormium* sp.	O
Cotoneaster sp.	O	*Viburnum* sp.	O	*Phacelia tanacetifolia* Benth.	O
Prunus sp.	O	*Sophora microphylla* Ait.	O	*Lupinus arboreus* Sims	O
Viburnum sp.	O	*Acer* sp.	O	*Brassica* sp.	O
Sophora microphylla Ait.	O	*Phormium* sp.	O		
Acer sp.	O	*Cordyline australis* (Forst. f.) Endl.	O		
Phormium sp.	O	*Eucalptus* sp.	O		
Cordyline australis (Forst. f.) Endl.	O	*Amaranthus* spp.	O		
Eucalyptus sp.	O	*Helianthus* spp.	O		
Chrysanthemum sp.		*Cucurbita* sp.	O		

2.1.3 Dissection

To assess gut fullness and female gravidness each fly was dissected. This involved placing each insect on a glass microscope slide and removing its head, thorax and wings. The abdomen was then teased gently apart using a mounted needle and fine forceps, releasing the contents over the slide.

2.1.4 Female gravidness

A drop of 70% alcohol was added and the presence or absence of mature eggs was noted in the female flies and the number of eggs counted. If there were more than 100 eggs then they were estimated to the nearest tenth.

2.1.5 Pollen preference and gut fullness

The gut contents were stirred gently to separate and spread the pollen grains and three drops of warm jelly was added. The jelly comprised of a few drops of saffranine, 7.0 g gelatine, 42.0 ml cold tap water, 50.0 ml glycerine and 0.5 g carbolic acid (phenol). A glass coverslip was placed over the slide and the slides were set aside until the jelly solidified. Clear nail polish was then placed around the edges of the coverslip to seal the slide.

The forceps and needle were sterilised using alcohol and wiped in between each dissection to prevent pollen contamination between samples.

Five longitudinal scans of the slide, spread equidistantly across it were made at 100 x magnification. Gut fullness was assessed as accurately as possible, without detailed counting at the higher pollen categories, as being in one of seven frequency classes (0 = no pollen grains, 1 = 1-10 grains, 2 = 11-100 grains, 3 = 101-1000 grains, 4 = 1001-3000 grains, 5 = 3001-5000 grains, 6 = >5,000 grains). All pollen seen was identified to at least the family level (400 x magnification used when necessary). The amount of each type of pollen was also assessed and given a percentage value. Reference slides of pollen from species of flowering plants present were made as aids to pollen identification and a simple pollen guide was made for quick reference (refer to Appendix 1). Reference books by Moore, Webb and Collinson (1991) and Moar (1993) were used, and Dr. Neville Moar was also consulted several times (see acknowledgments).

2.1.6 Analysis

Pseudo-replicates (i.e., traps within replicates) were averaged to obtain a mean for each of the three replicates. The number of eggs were log transformed ($\log_e$ (number of eggs + 1)) prior to analysis to stabilise the variance. The frequency of the number of different pollen types consumed was calculated and the frequency of 6-9 pollen types were pooled. The mean number of hover flies per trap, the number of eggs in females, the medians of gut fullness and the medians of the number of different pollen types consumed were compared between the horticultural, arable and phenology sites using the Kruskal-Wallis non-parametric test.

2.2 Phenology

2.2.1 Site description

This work is part of a long term phenology study in which hover flies have been captured from five yellow plastic two-litre containers (as above) placed along a fence line on the Lincoln University Cropping Farm, 10 metres apart. This site is on the same land as the traps used from the arable site but did not consist of traps with their sides painted green (Fig. 2.1). This site had similar plant species present as the arable site (Table 2.1).

2.2.2 Experimental procedure

Hover fly data collected approximately weekly from September 8, 1994 to July 25, 1996 has been included in this investigation and this monitoring is continuing. Two dates approximately two weeks apart were chosen from each month, in which most of the hover fly sex and species data was present. However, some of the hover flies were not present to use for dissection (Table 2.3). The hover flies were removed from the traps and placed in a vial containing 70% ethanol. Later, in the laboratory, they were identified to species and sexed by the methods described in Section 2.1.2.

A maximum sample of five hover flies of each sex, for each species was dissected for each sample date and female gravidness, gut fullness and pollen preference were assessed, according to the methods described in Section 2.1.4 and 2.1.5.

2.2.3 Analysis

The mean number of flies (five traps) for each sampling occasion was entered into a spreadsheet (Microsoft Excel) to produce a summary of fly numbers over a year. Estimates of egg and gut fullness data were pooled into 20-day periods and the trend lines were drawn using a running mean of the three adjacent 20-day periods. The frequency of the number of different pollen types consumed was calculated and the frequency of 6-9 pollen types were pooled. Dates throughout the year were pooled into seasons (summer was taken as December to February, autumn as March to May, winter as June to August and spring as September to November). The number of different pollen types was compared for species and gender between seasons using the Kruskal-Wallis non-parametric test.

Table 2.3 Weeks during 1994-1996 in which hover flies were available for dissection (o indicates when hover flies were present, x indicates when no hover flies were present for that week's sample).

Date and week sample	1994	1995	1996
Jan week 1		o	o
Jan week 2		x	o
Feb week 1		o	o
Feb week 2		o	x
March week 1		o	o
March week 2		o	o
April week 1		o	o
April week 2		o	o
May week 1		o	o
May week 2		x	o
June week 1		o	o
June week 2		o	o
July week 1		o	o
July week 2		o	o
Aug week 1		o	
Aug week 2		o	
Sept week 1	x	o	
Sept week 2	x	o	
Oct week 1	o	o	
Oct week 2	x	o	
Nov week 1	x	x	
Nov week 2	o	o	
Dec week 1	x	o	
Dec week 2	x	o	

Chapter 3.

Results

3.1 Phenology

3.1.1 Numbers of hover flies captured, number of eggs in female flies and gut fullness throughout the year

Up to mid-December during 1994 and 1995 catches of *M. fasciatum* were relatively low, reaching a maximum, on average, of 0.05 per trap/day in 1994. However, after mid-December catches were much higher, with a peak in late December-January 1994 and a smaller peak in late December-January 1995 (Fig. 3.1).

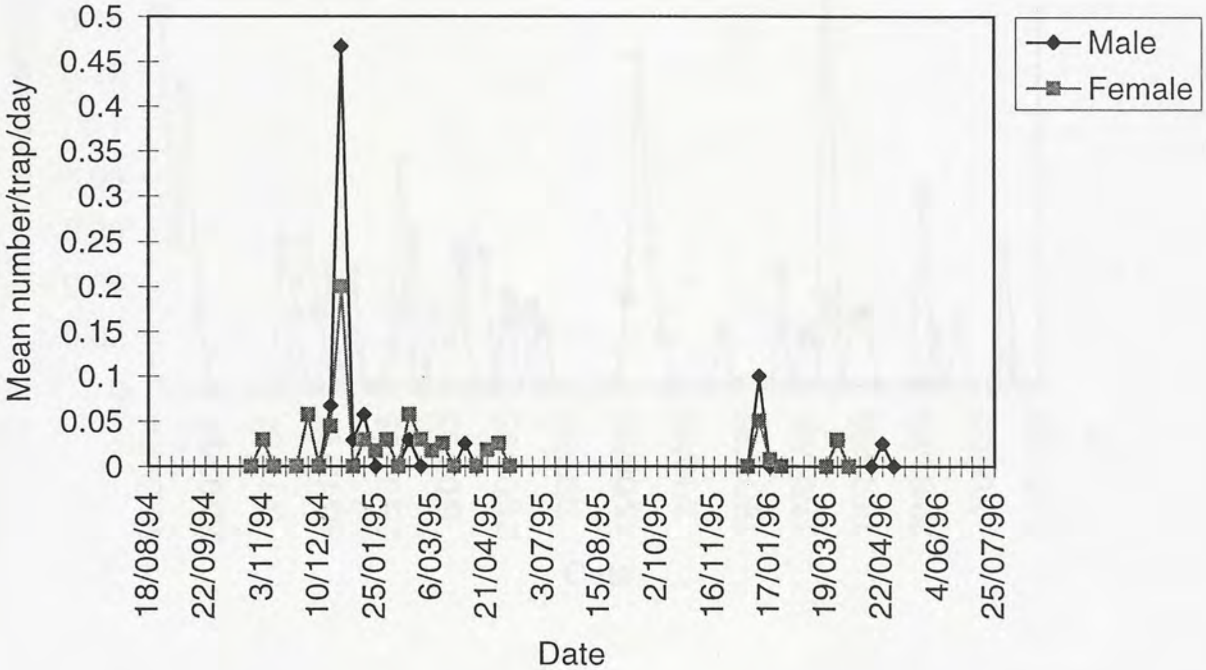

Fig. 3.1 Numbers of male and female *M. fasciatum* captured from August 18, 1994 to July 7, 1996 in phenology traps (green-sided) located at the Lincoln University Cropping Farm.

E. tenax numbers fluctuated throughout 1994, 1995 and 1996 with two obvious trends (Fig. 3.2). First, a peak of female *E. tenax* occurred in early August to mid-September during both 1994 and 1995 and no males were caught at this time. Second, a peak of male *E. tenax* in early January during both 1995 and 1996. Catches of female *M. novaezelandiae* reached a peak of 1.03 per trap/day on January 13, 1995 and at 0.17 per trap/day on March 19, 1996 (Fig. 3.3). In comparison, male *M. novaezelandiae* reached a peak of 0.51 per trap/day on December 30, 1994 and remained relatively low during 1995-1996 (Fig. 3.3).

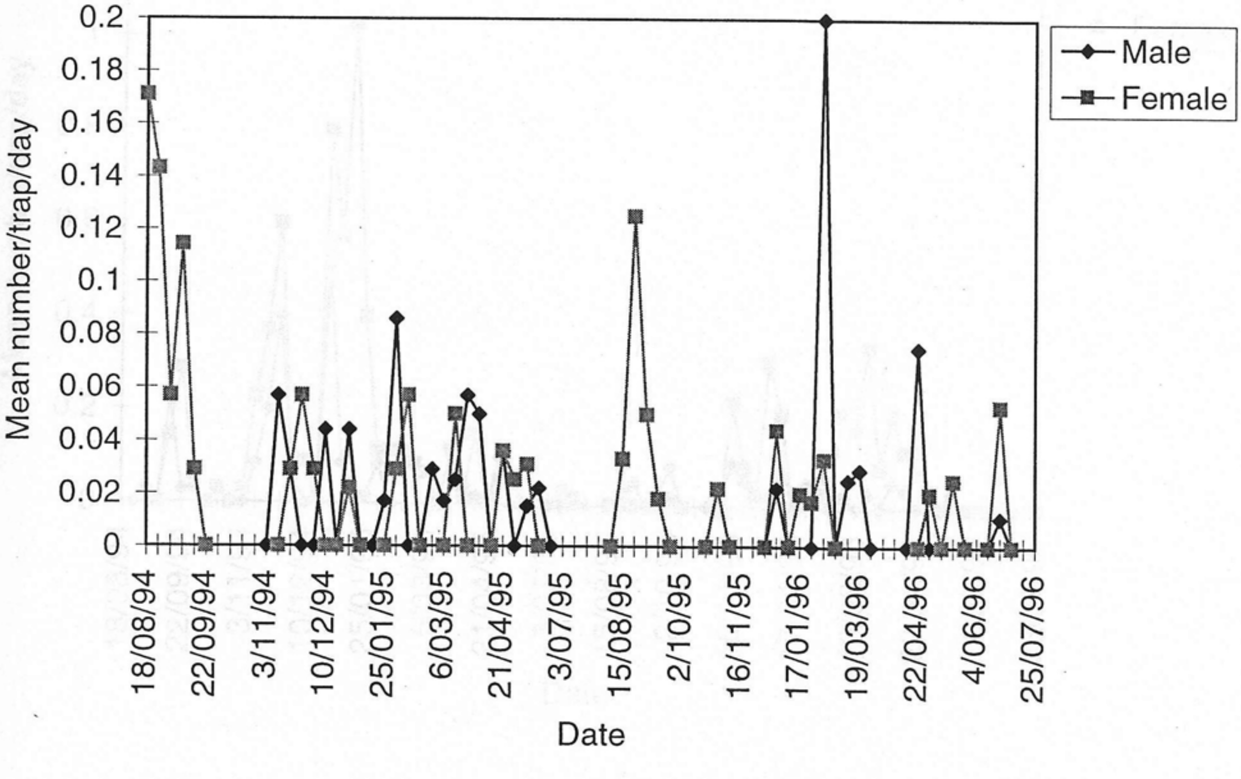

Fig. 3.2 Numbers of male and female *E. tenax* captured from August 18, 1994 to July 7, 1996 in phenology traps (green-sided) located at the Lincoln University Cropping Farm.

The number of eggs in female hover flies and gut fullness did not significantly (p>0.05) differ from March 19, 1996 to May 11, 1996 for each species. However, over each year gut fullness and the number of eggs in *M. novaezelandiae* and *M. fasciatum* were at their lowest during June to September, 1995. In contrast, gut fullness and the number of eggs in *E. tenax* were at their highest during June to September, 1995 with a peak of 108 eggs and 5.5 gut fullness in August (Fig. 3.4 & 3.5).

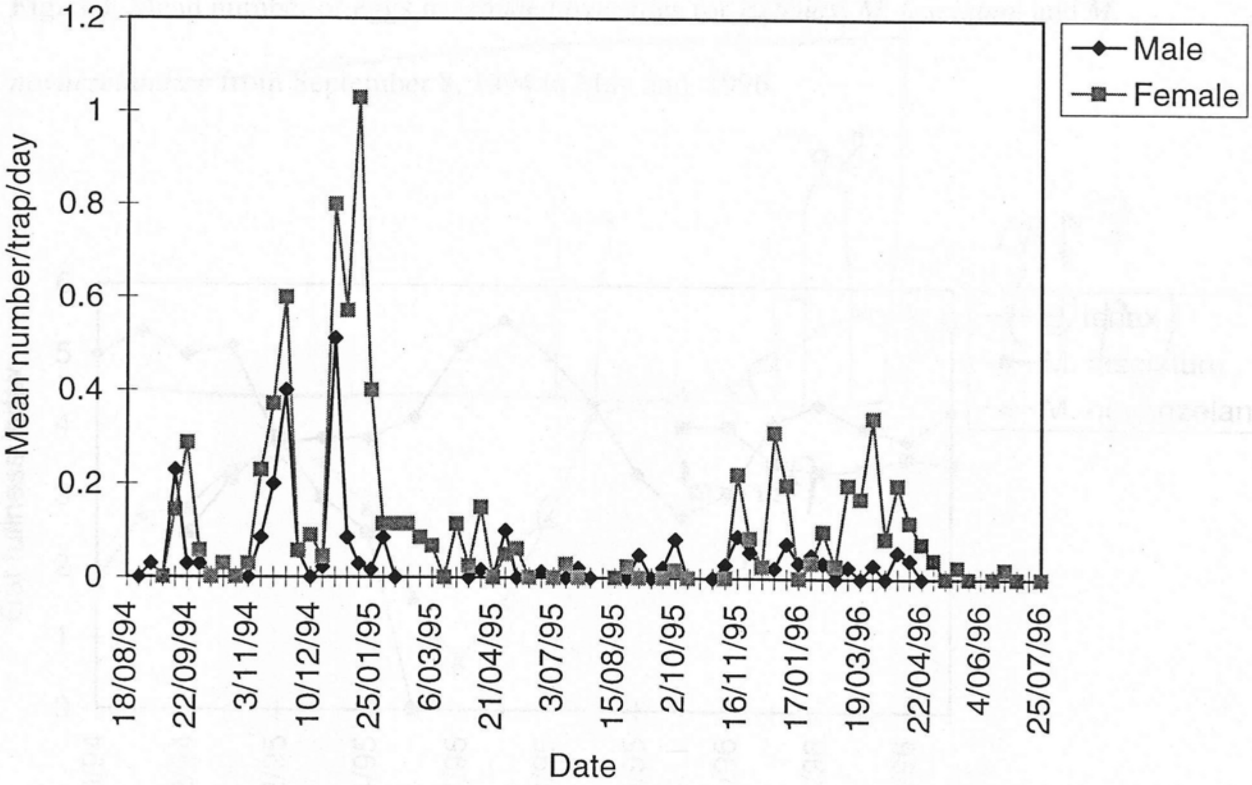

Fig. 3.3 Numbers of male and female *M. novaezelandiae* captured from August 18, 1994 to July 7, 1996 in phenology traps (green-sided) located at the Lincoln University Cropping Farm.

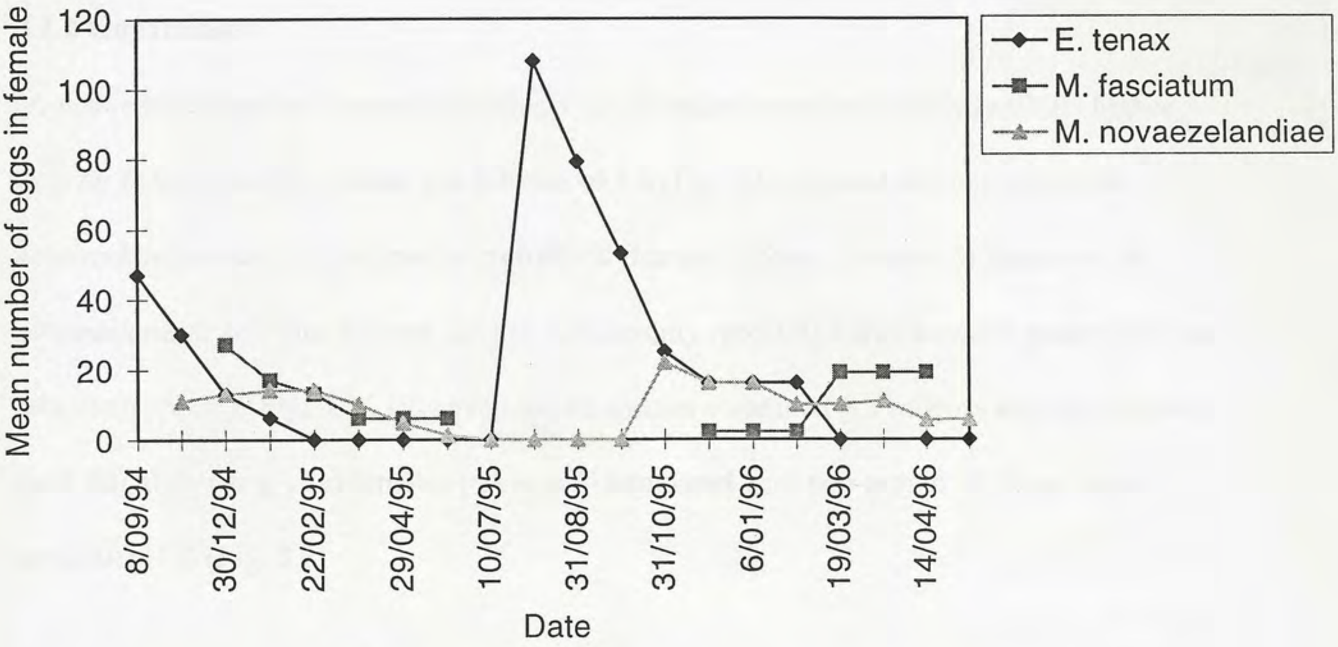

Fig. 3.4 Mean number of eggs in female hover flies for *E. tenax*, *M. fasciatum* and *M. novaezelandiae* from September 8, 1994 to May 2nd, 1996.

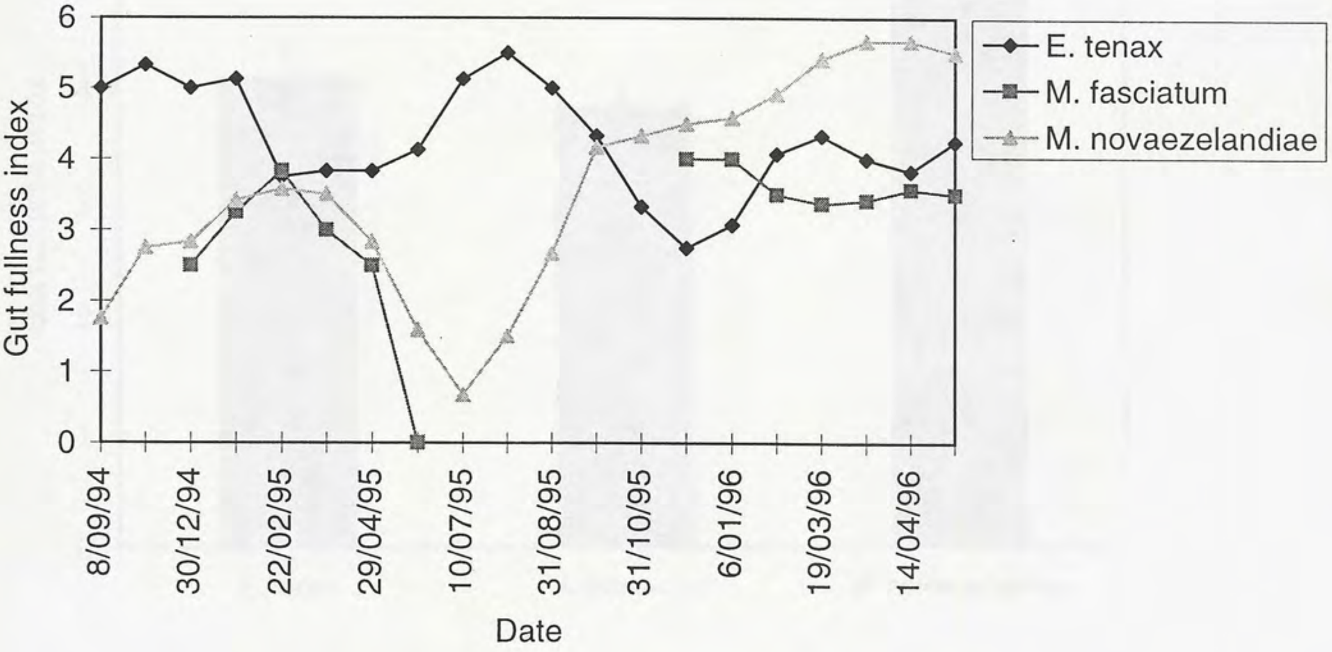

Fig. 3.5 Median gut fullness index per female for *E. tenax*, *M. fasciatum* and *M. novaezelandiae* from September 8, 1994 to May 2nd, 1996.

3.1.2 Gut fullness

M. novaezelandiae had a mean gut fullness of 5.0 which was significantly ($p<0.01$) higher than *M. fasciatum* with a mean gut fullness of 3.8 (Fig. 3.6). Gravid and non-gravid *M. novaezelandiae* had a significantly ($p<0.05$) higher gut fullness (mean = 5) than male *M. novaezelandiae* (4). Gut fullness did not significantly ($p>0.05$) differ between genders for the other two species (Fig. 3.7). However, for all species combined gut fullness was significantly ($p<0.00$) higher in gravid females (mean = 5) compared with non-gravid (4.5) and male hover flies (4) (Fig. 3.8).

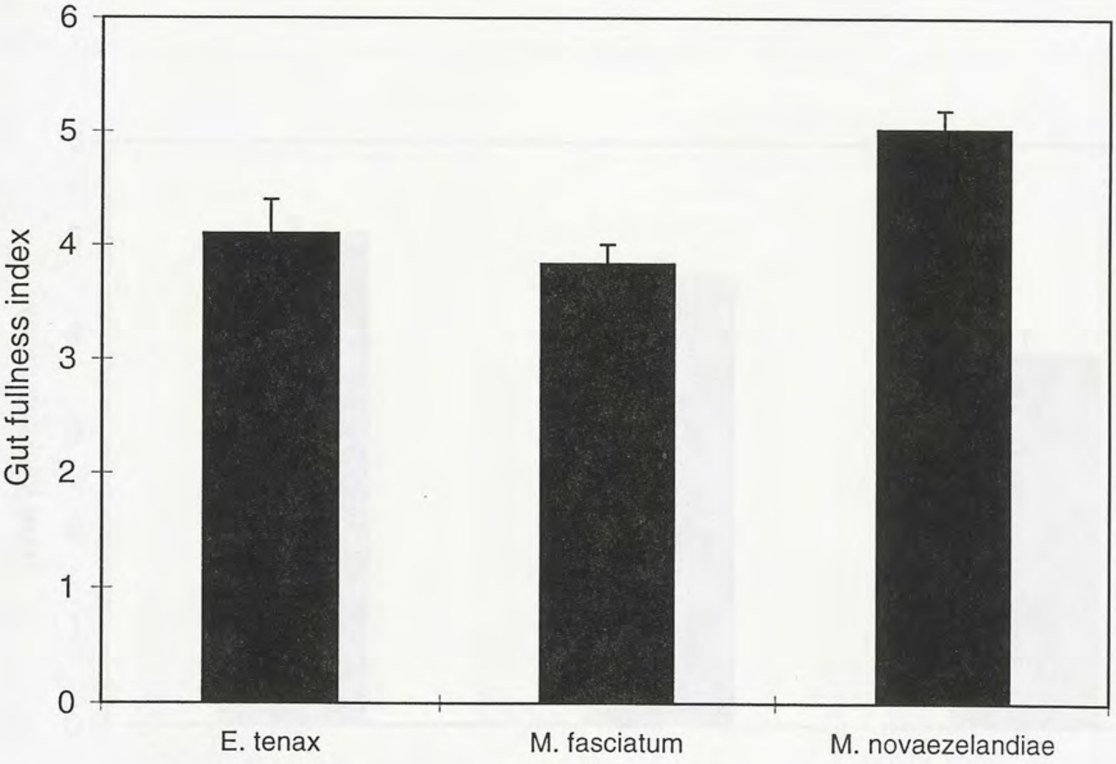

Fig. 3.6 The mean (± SE) gut fullness index for *E. tenax*, *M. fasciatum* and *M. novaezelandiae*.

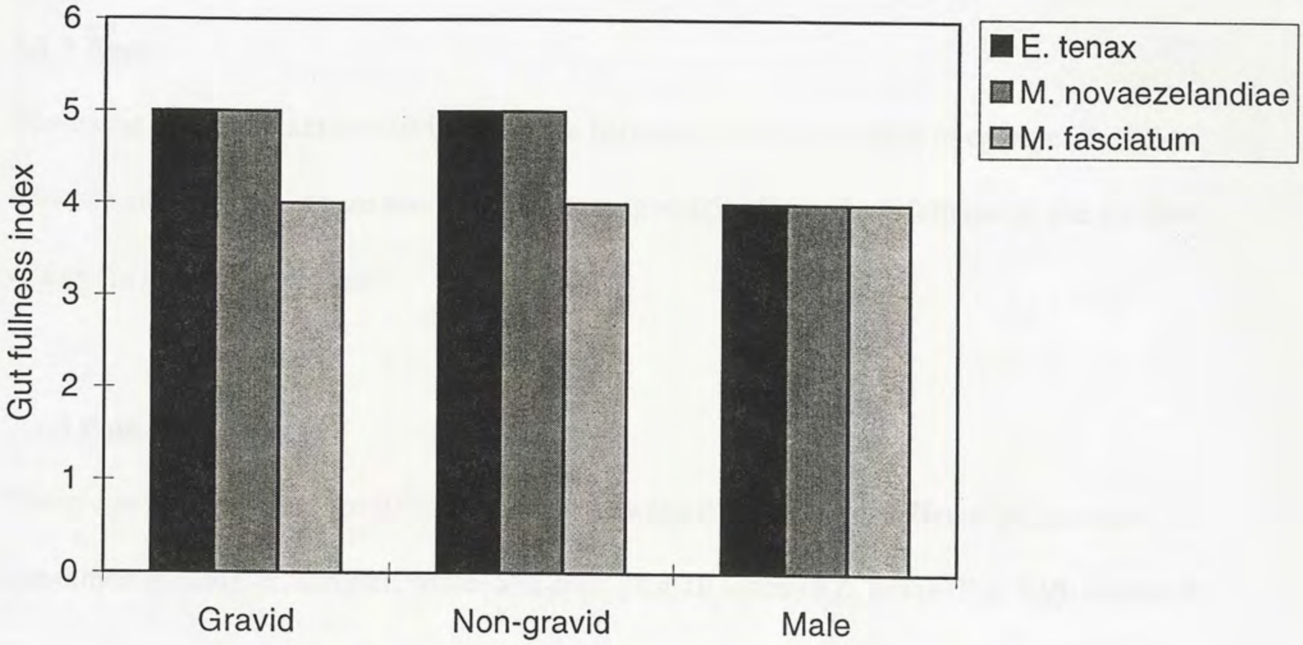

Fig. 3.7 The median gut fullness index for male and female (gravid and non-gravid) *E. tenax*, *M. fasciatum* and *M. novaezelandiae*.

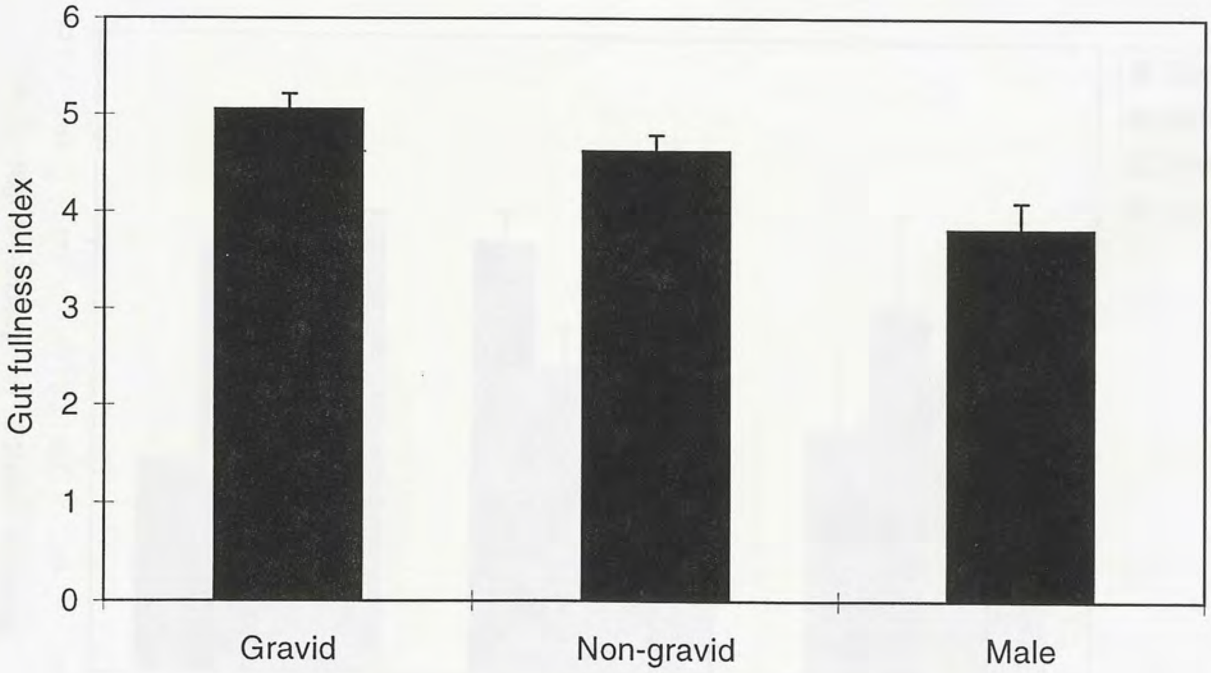

Fig. 3.8 Median (± SE) gut fullness index for male and female (gravid and non-gravid) hover flies over all species.

3.1.3 Eggs

There was no significant (p>0.05) difference between the mean number of eggs per female between each species. There was no significant (p>0.05) effect of gut fullness on the number of eggs in female hover flies.

3.1.4 Pollen frequency

There was no significant (p>0.05) difference between the number of different pollen types consumed in summer, autumn, winter and spring for all sexes of *E. tenax* (Fig. 3.9). Gravid *M. fasciatum* consumed a significantly (p<0.05) higher number of pollen types in summer compared to autumn (Fig. 3.10). There were no other significant (p>0.05) differences in the number of different pollen types consumed for non-gravid and male *M. fasciatum* over seasons although data was not present for winter and spring (Fig. 3.10).

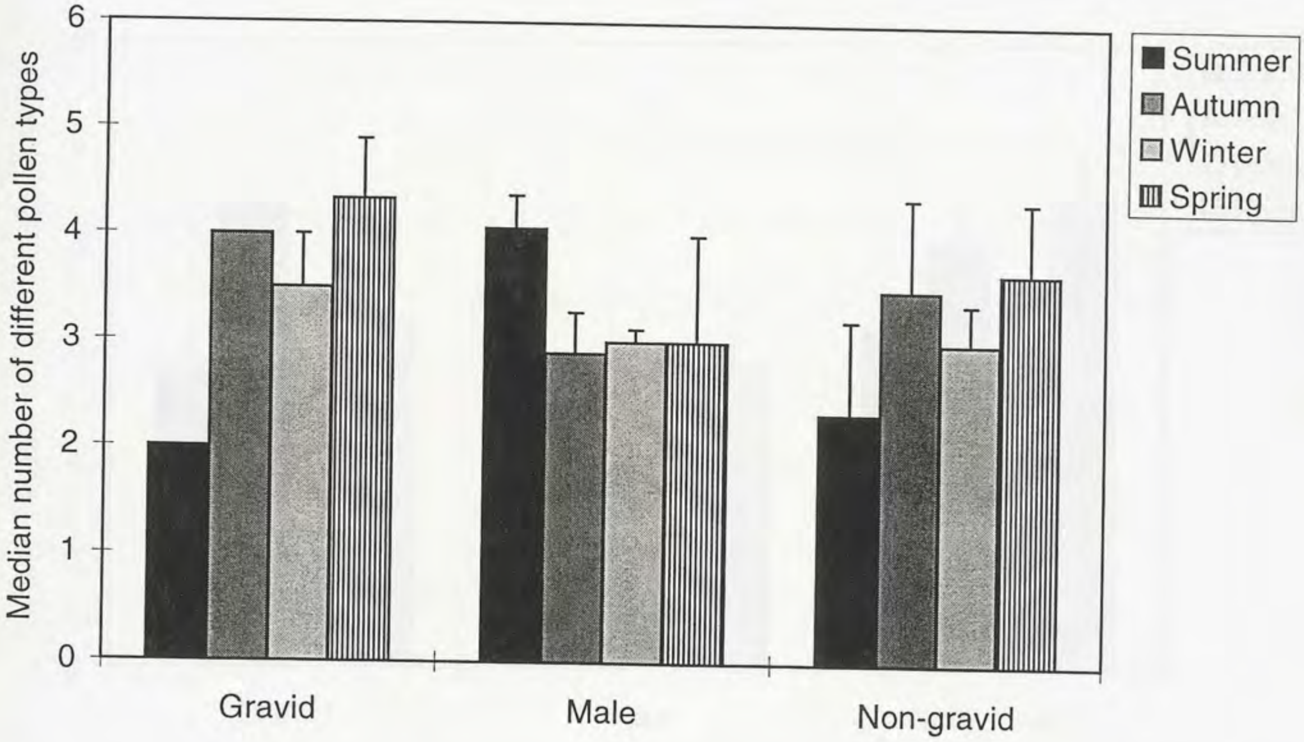

Fig. 3.9 Median (± SE) number of different pollen types over seasons for *E. tenax*.

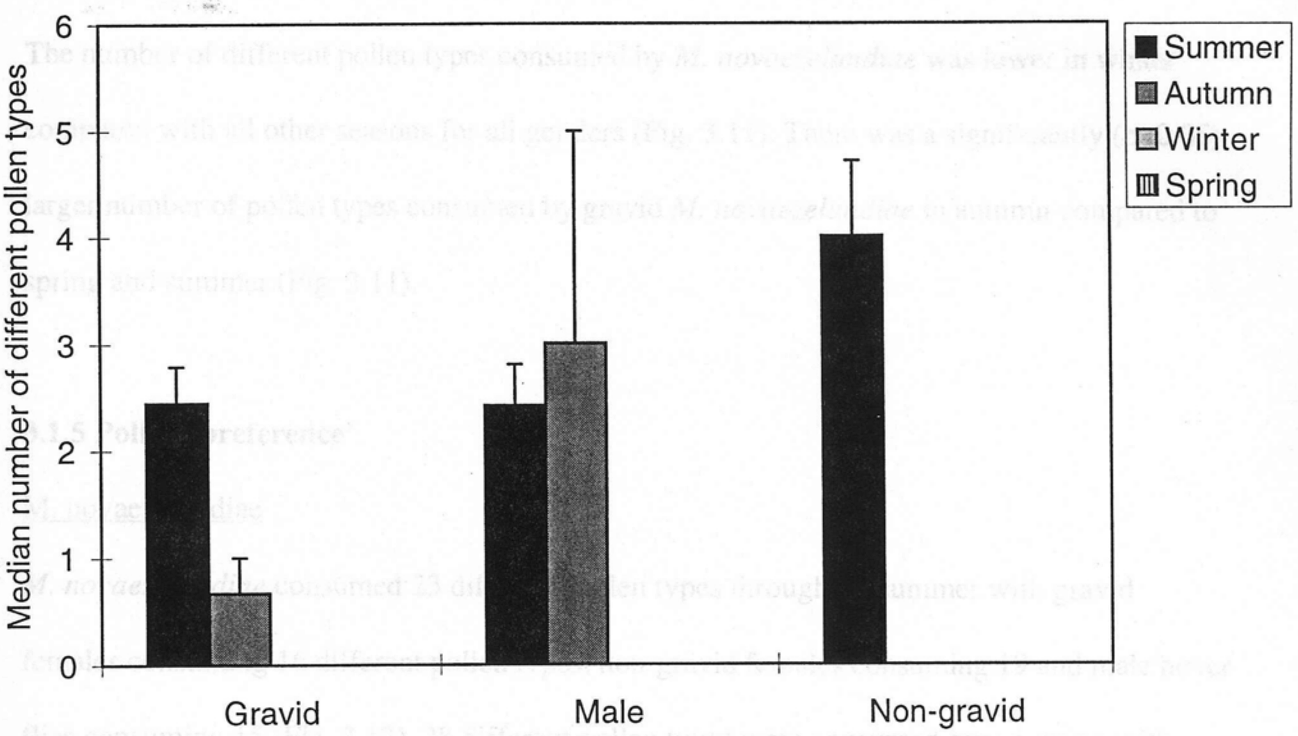

Fig. 3.10 Median (± SE) number of different pollen types over summer and autumn for *M. fasciatum.*

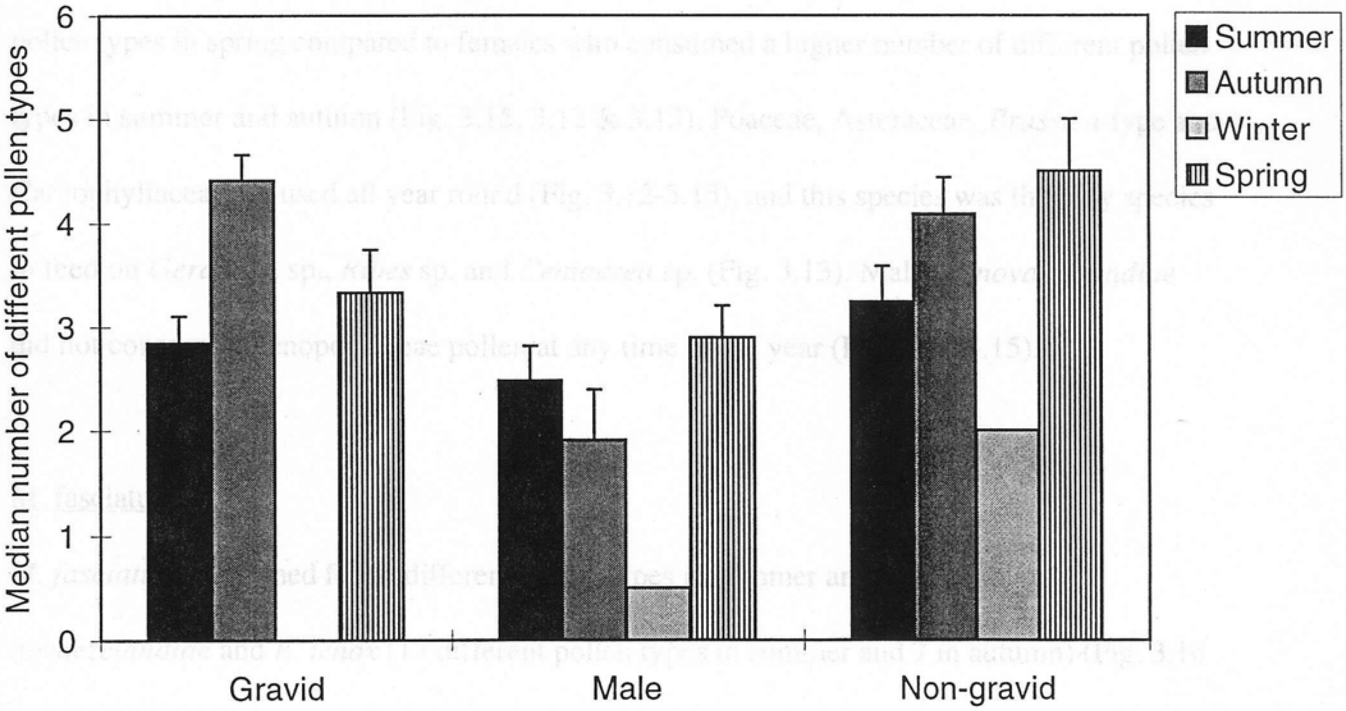

Fig 3.11 Median (± SE) number of different pollen types over seasons for *M. novaezelandiae.*

The number of different pollen types consumed by *M. novaezelandiae* was lower in winter compared with all other seasons for all genders (Fig. 3.11). There was a significantly ($p<0.05$) larger number of pollen types consumed by gravid *M. novaezelandiae* in autumn compared to spring and summer (Fig. 3.11).

3.1.5 Pollen 'preference'

M. novaezelandiae

M. novaezelandiae consumed 23 different pollen types throughout summer with gravid females consuming 16 different pollen types, non-gravid females consuming 19 and male hover flies consuming 15 (Fig. 3.12). 28 different pollen types were consumed over autumn with gravid females consuming 19, non-gravid females consuming 22 and male hover flies consuming only 9 (Fig. 3.13). In contrast, 4 different pollen types were consumed in winter by this species and 17 in spring (Fig. 3.14 & 3.15). Males consumed a higher number of different pollen types in spring compared to females who consumed a higher number of different pollen types in summer and autumn (Fig. 3.15, 3.12 & 3.13). Poaceae, Asteraceae, *Brassica*-type and Caryophyllaceae are used all year round (Fig. 3.12-3.15), and this species was the only species to feed on *Geranium* sp., *Ribes* sp. and *Centaurea* sp. (Fig. 3.13). Male *M. novaezelandiae* did not consume Chenopodiaceae pollen at any time of the year (Fig. 3.12-3.15).

M. fasciatum

M. fasciatum consumed fewer different pollen types in summer and autumn than *M. novaezelandiae* and *E. tenax* (13 different pollen types in summer and 7 in autumn) (Fig. 3.16 & 3.17). There was no obvious trends between the number of pollen types consumed between gender (Fig. 3.16 & 3.17). M. *fasciatum* was the only species not to feed on pine (*Pinus* sp.) (Fig. 3.16 & 3.17), although winter and spring data is not present. Gravid female *M. fasciatum* were the only flies to feed on *Rumex* sp. (Fig. 3.16) and this species of hover fly fed on *Plantago sp.* and *Phacelia tanacetifolia* Benth. in summer whereas *M. novaezelandiae* did not (Fig. 3.16 & 3.12).

E. tenax

E. tenax consumed 15 species all year round with male flies consuming a wider range of pollen types in summer and autumn and female flies consuming a wider range of pollen types in winter and spring (Fig. 3.18-3.21). This is an opposite trend to that for *M. novaezelandiae*. *E. tenax* consumed a higher number of different pollen types in winter compared with *M. novaezelandiae* which included *Salix* sp., *Erica* sp. and pine (Fig. 3.20 & 3.14)). In contrast, *E. tenax* did not consume *Phacelia* (Fig. 3.18-3.21).

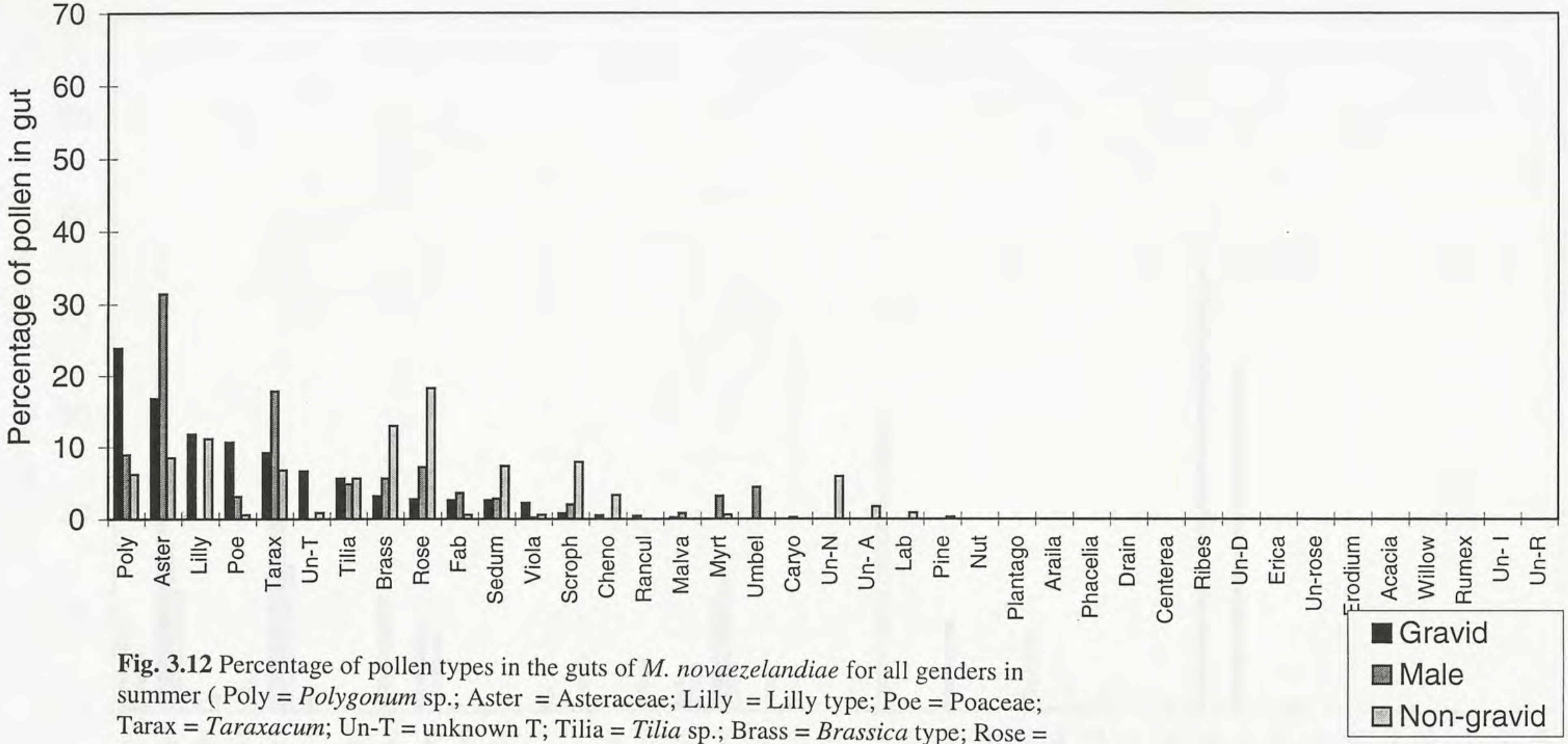

Fig. 3.12 Percentage of pollen types in the guts of *M. novaezelandiae* for all genders in summer (Poly = *Polygonum* sp.; Aster = Asteraceae; Lilly = Lilly type; Poe = Poaceae; Tarax = *Taraxacum*; Un-T = unknown T; Tilia = *Tilia* sp.; Brass = *Brassica* type; Rose = Rosaceae; Fab = Fabaceae; Sedum = *Sedum* sp.; Viola = *Viola* sp.; Scroph = Scrophulaceae; Cheno = Chenopodiaceae; Rancul = Ranuculaceae; Malva = Malvaceae; Myrt = Myrtaceae; Umbel = Umbelliferae; Caryo = Caryophyllaceae; Un-N = unknown N; Un-A = unknown A; Lab = Labiatae; Pine = *Pinus* sp.; Nut = Nut type; Plantago = *Plantago* sp.; Araila = Arailaceae; Phacelia = *Phacelia tanacetifolia*; Drain = *Geranium* sp.; Centaurea = *Centaurea* sp.; Ribes = *Ribes* sp.; Un-D = unknown D; Erica = Ericaceae; Un-rose = unknown rosaceae; Erodium = *Erodium* sp.; Acacia = *Acacia* sp.; Willow = *Salix* sp.; Rumex = *Rumex* sp.; Un-I = unknown I; Un-R = unknown R).

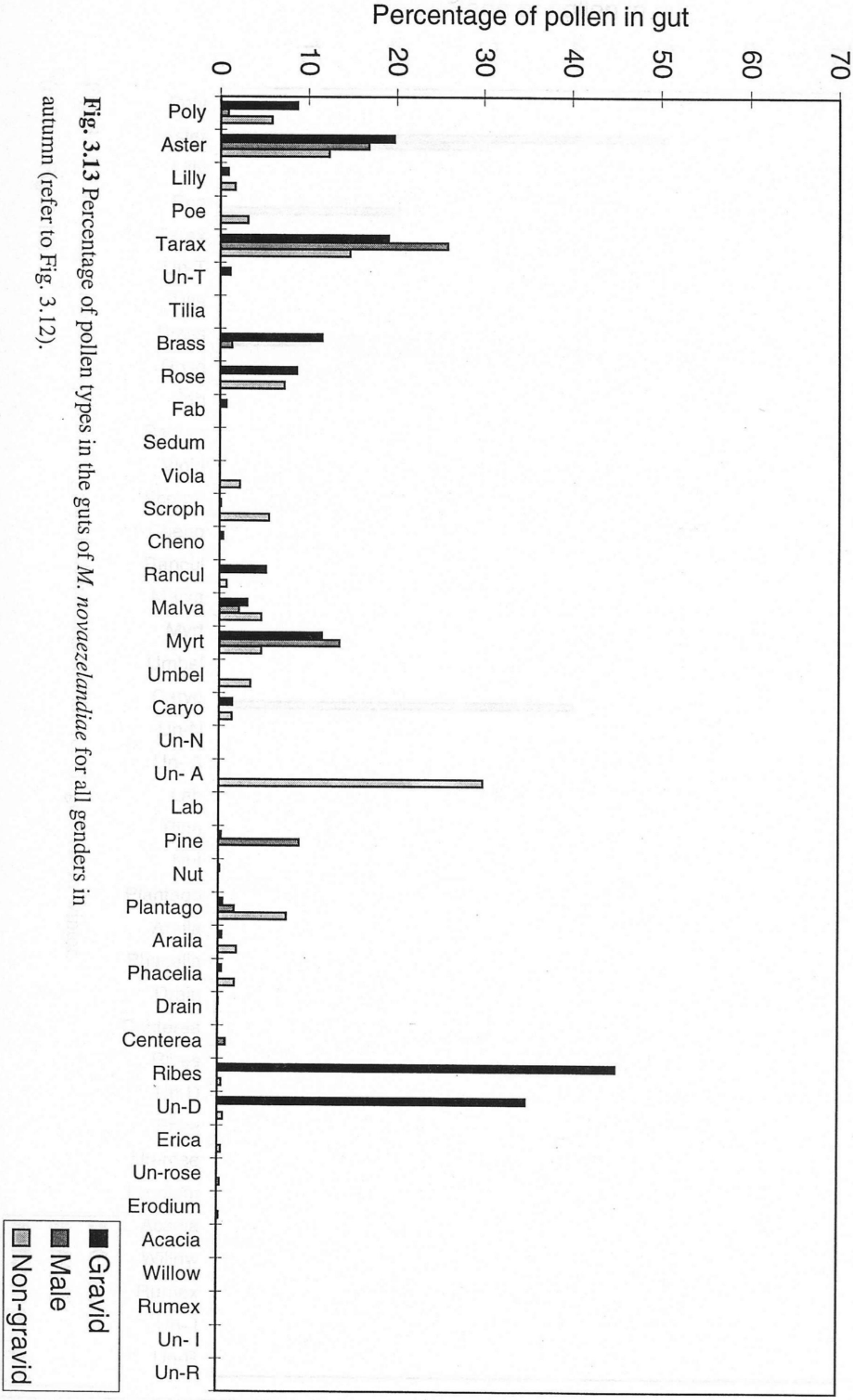

Fig. 3.13 Percentage of pollen types in the guts of *M. novaezelandiae* for all genders in autumn (refer to Fig. 3.12).

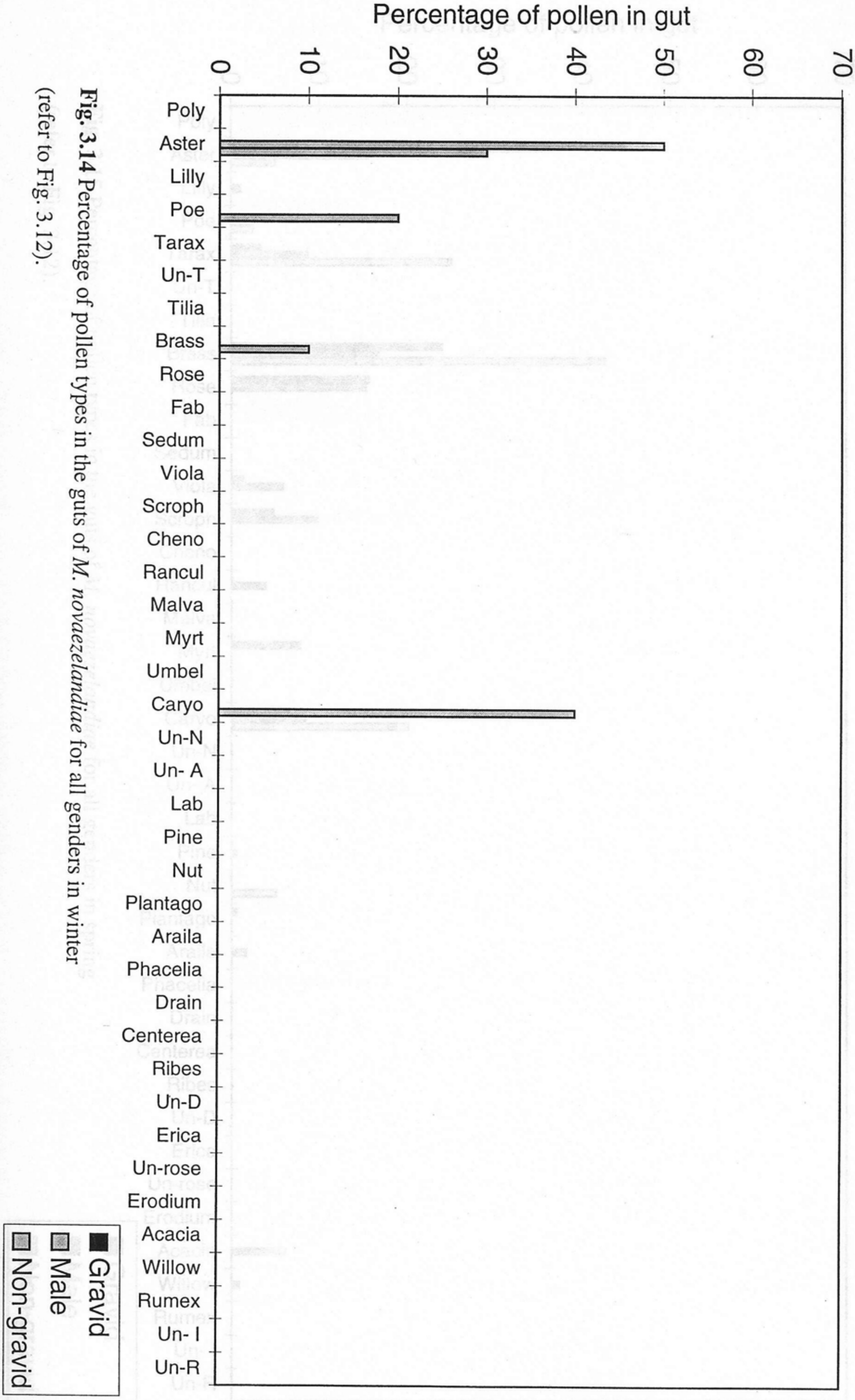

Fig. 3.14 Percentage of pollen types in the guts of *M. novaezelandiae* for all genders in winter (refer to Fig. 3.12).

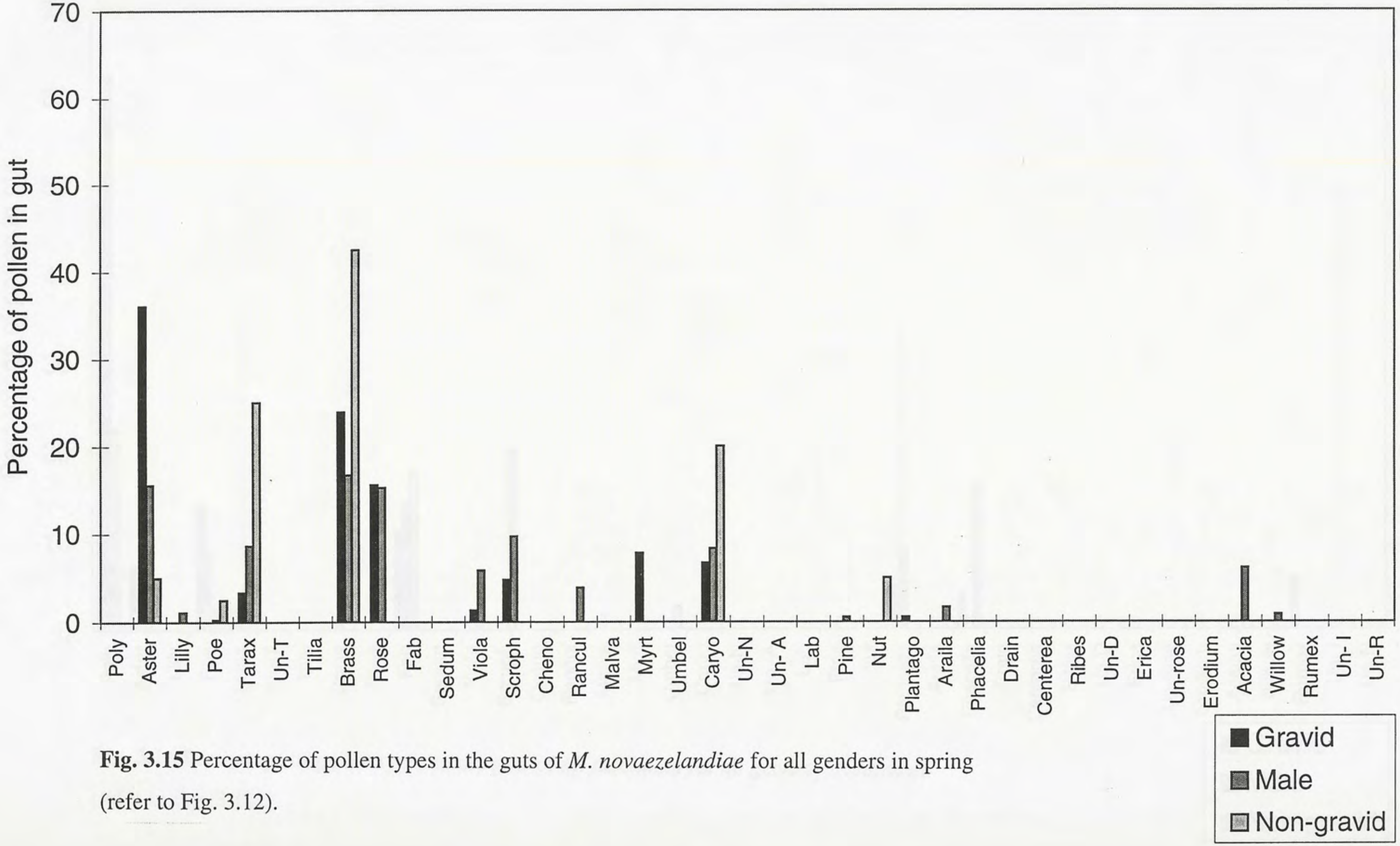

Fig. 3.15 Percentage of pollen types in the guts of *M. novaezelandiae* for all genders in spring (refer to Fig. 3.12).

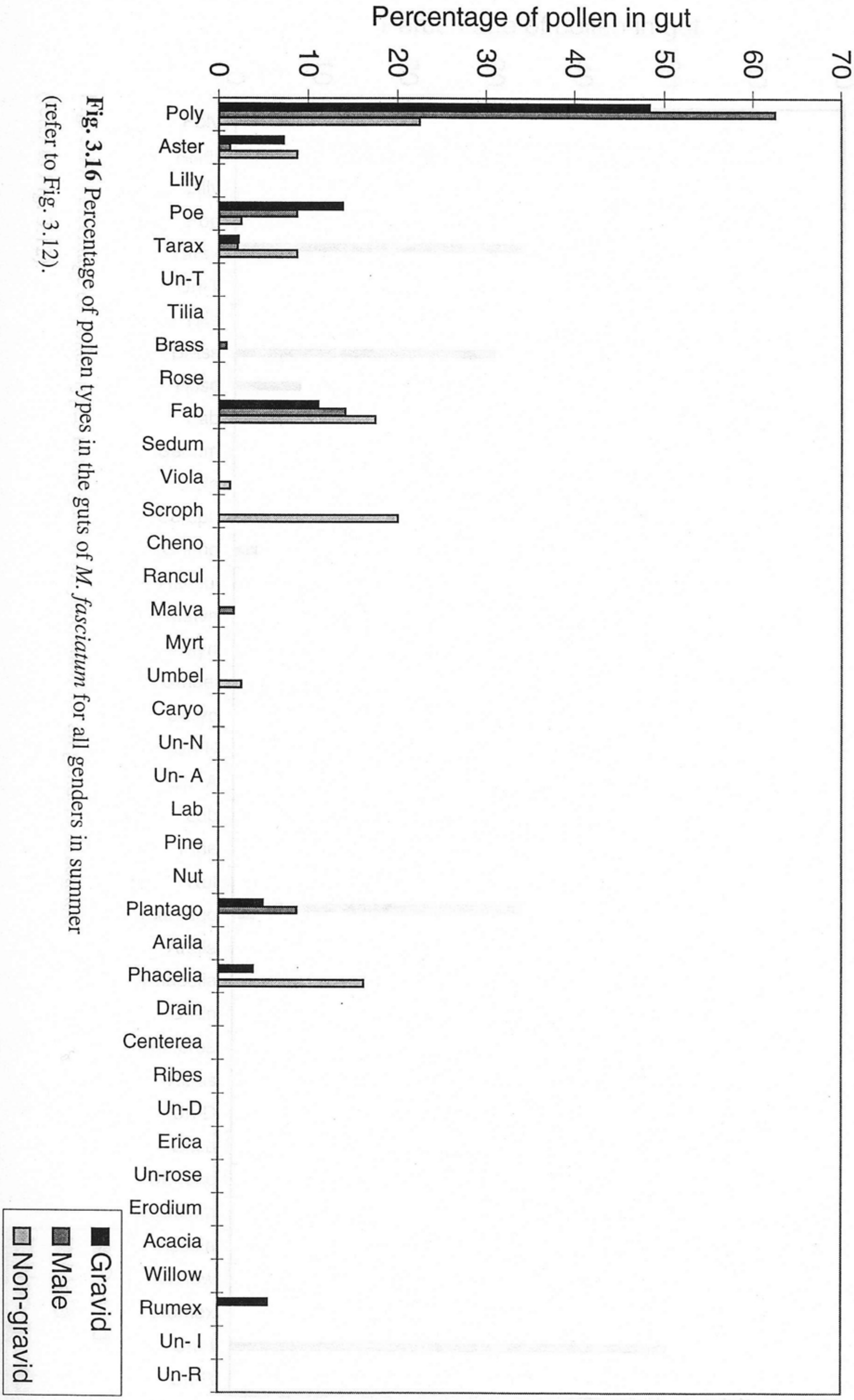

Fig. 3.16 Percentage of pollen types in the guts of *M. fasciatum* for all genders in summer (refer to Fig. 3.12).

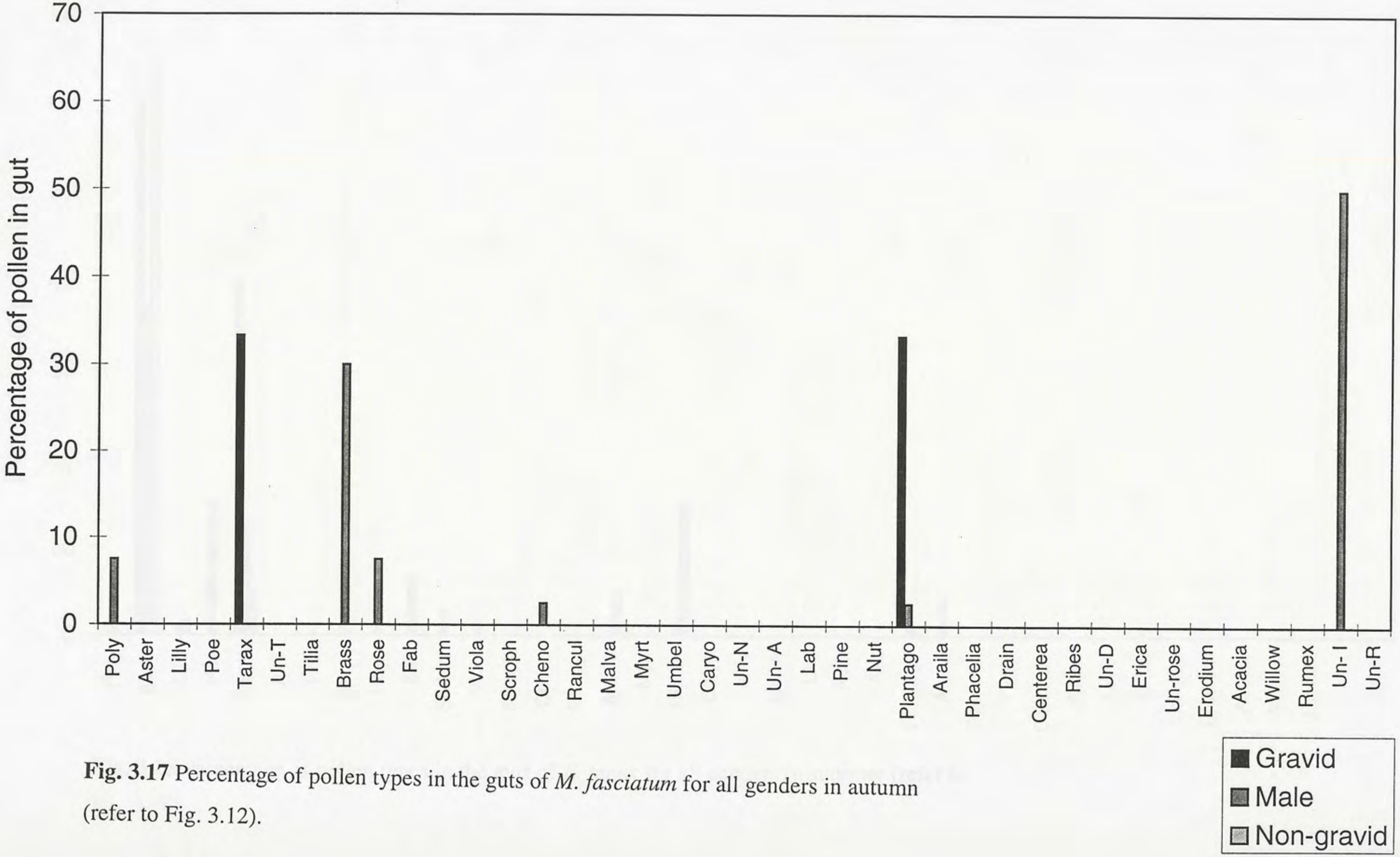

Fig. 3.17 Percentage of pollen types in the guts of *M. fasciatum* for all genders in autumn (refer to Fig. 3.12).

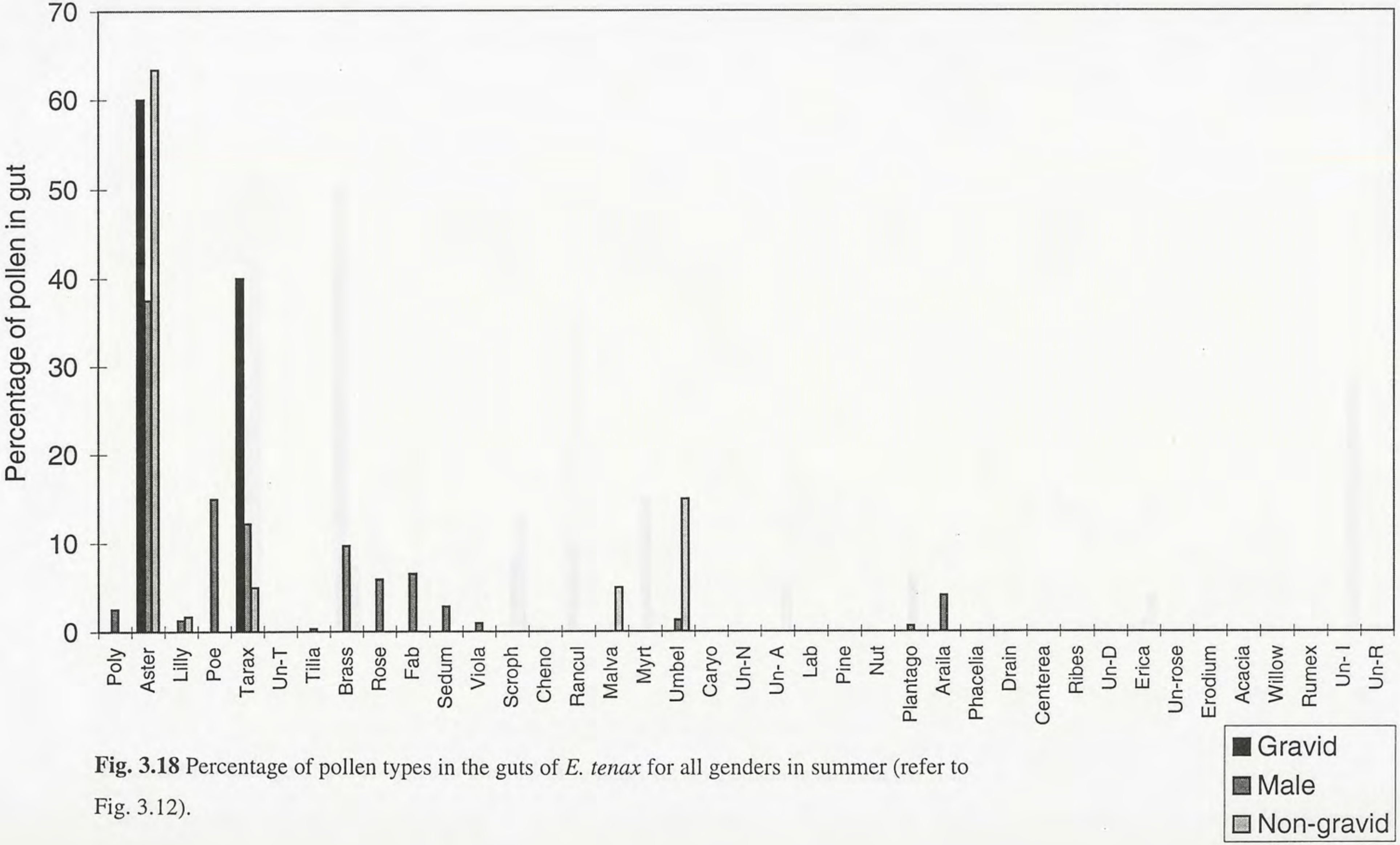

Fig. 3.18 Percentage of pollen types in the guts of *E. tenax* for all genders in summer (refer to Fig. 3.12).

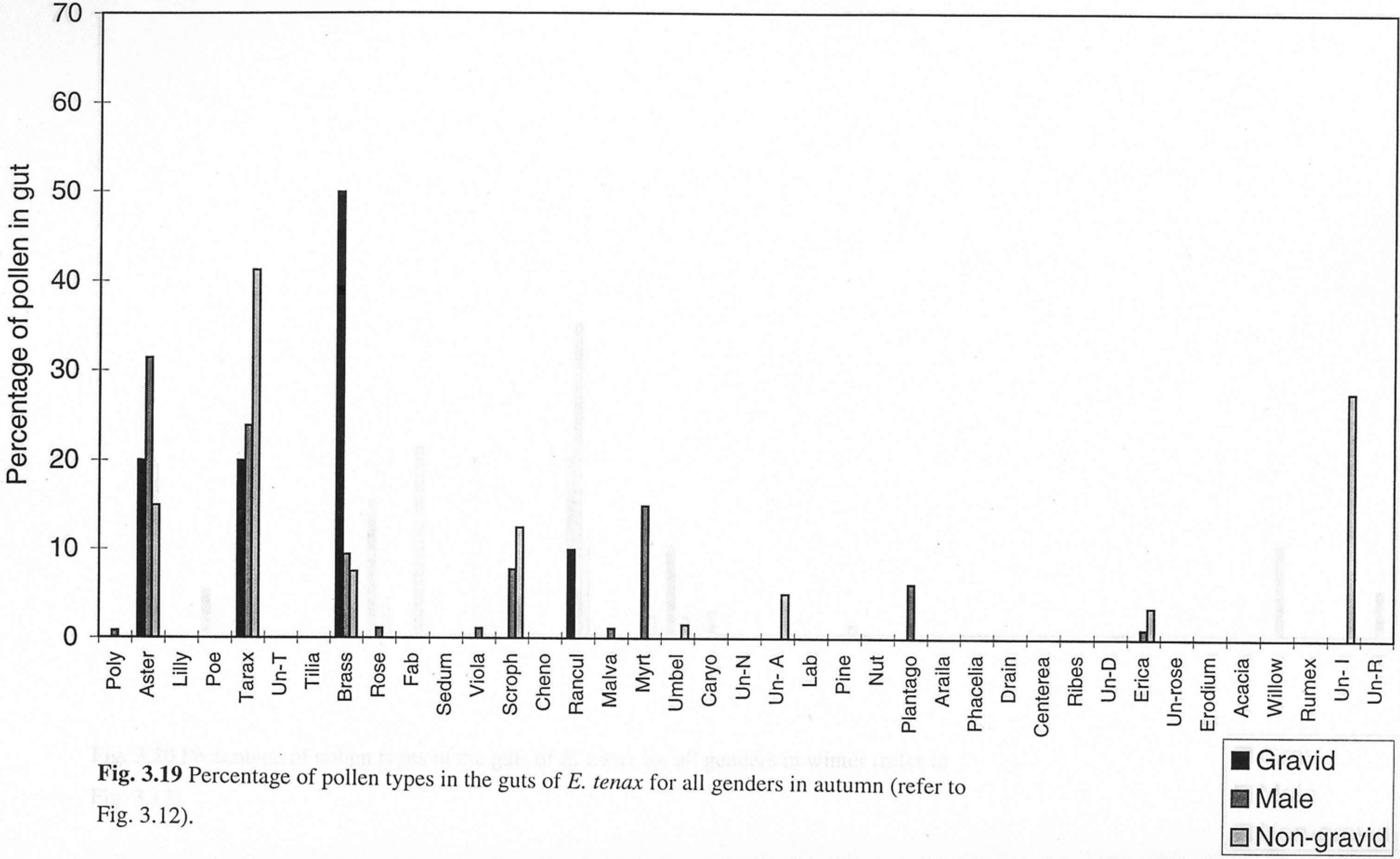

Fig. 3.19 Percentage of pollen types in the guts of *E. tenax* for all genders in autumn (refer to Fig. 3.12).

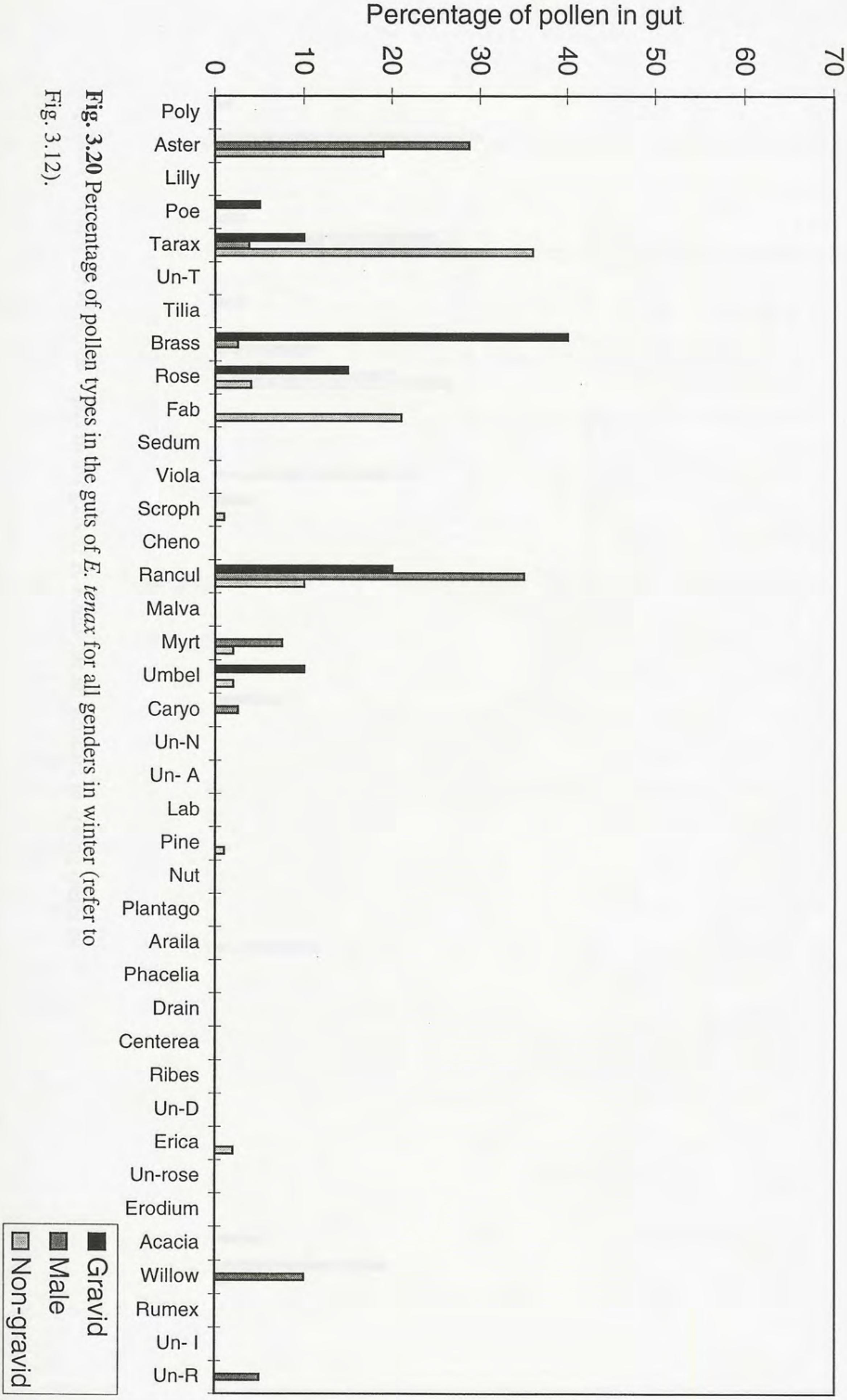

Fig. 3.20 Percentage of pollen types in the guts of *E. tenax* for all genders in winter (refer to Fig. 3.12).

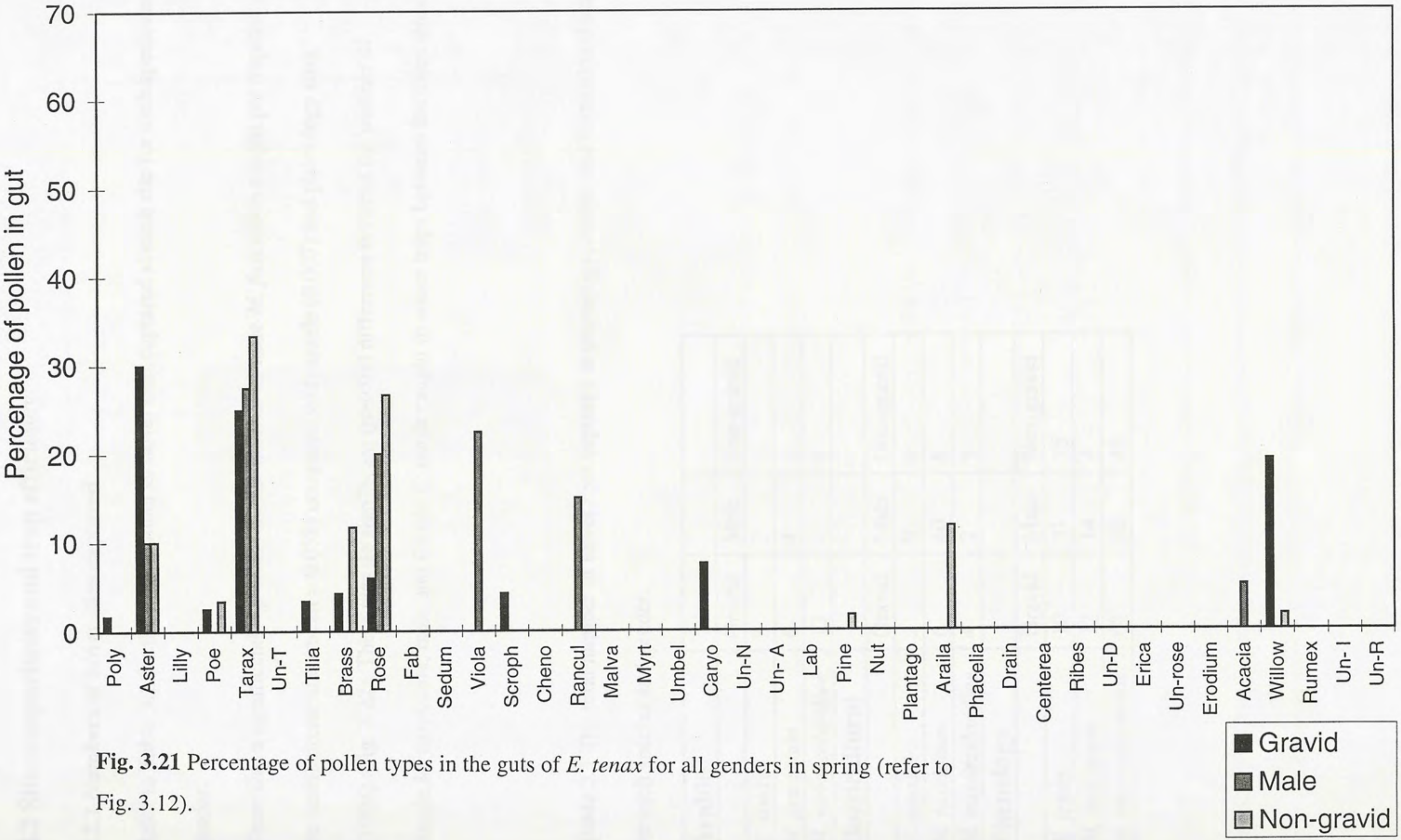

Fig. 3.21 Percentage of pollen types in the guts of *E. tenax* for all genders in spring (refer to Fig. 3.12).

3.2 Site comparisons and trap efficiency

3.2.1 Numbers of hover flies captured

Refer to Table 3.1 for the total number of hover flies captured at each site for each species and gender.

There was a significantly ($p<0.05$) higher number of male *M. fasciatum* caught per trap/day at the horticultural site (mean = 0.058) compared with arable (0.007) and phenology sites (0.004) (Fig. 3.22). There was no significant ($p>0.05$) difference between the number of female *M. fasciatum*, male and female *E. tenax* caught in water traps between the three sites.

Table 3.1 The total number of hover flies captured at phenology, arable and horticultural sites for each species and gender.

Arable			
	Gravid	Male	Non-gravid
E. tenax	3	7	2
M. fasciatum	6	4	1
M. novaezelandiae	13	4	6
Horticultural			
	Gravid	Male	Non-gravid
E. tenax	2	9	0
M. fasciatum	6	40	8
M. novaezelandiae	4	2	9
Phenology			
	Gravid	Male	Non-gravid
E. tenax	10	31	15
M. fasciatum	12	14	4
M. novaezelandiae	68	56	45

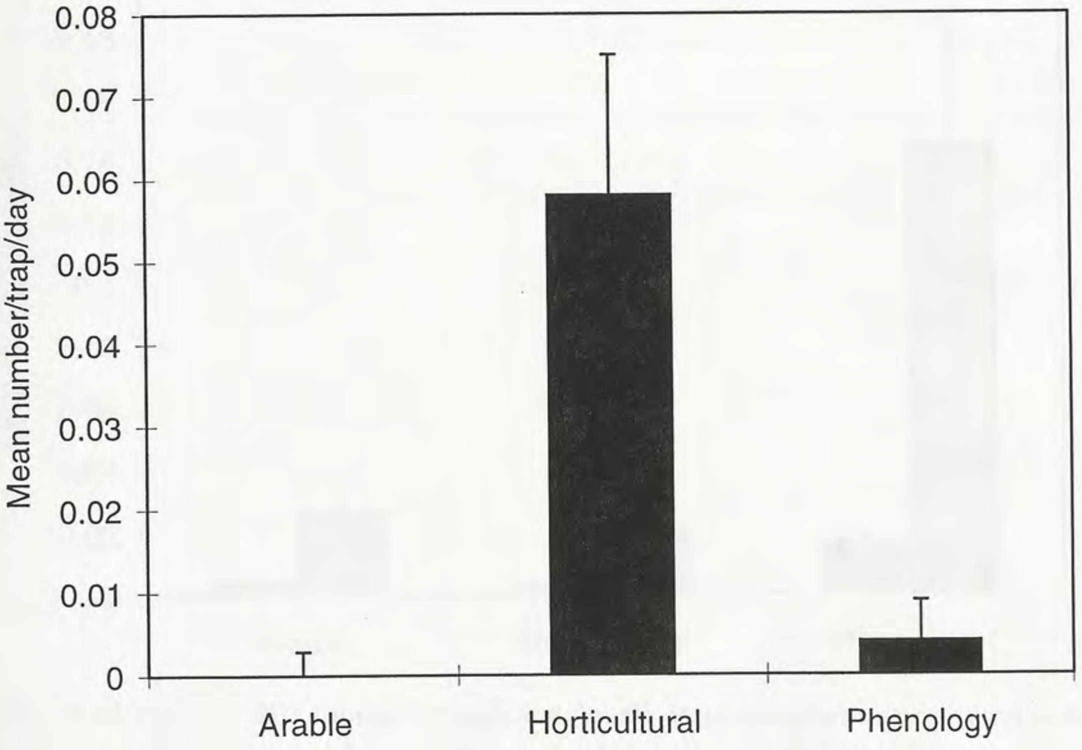

Fig 3.22 Mean (± SE) number of male *M. fasciatum* captured at arable, phenology and horticultural sites from March 19, 1996 to May 11, 1996.

There was significantly ($p<0.05$) more male *M. novaezelandiae* at the phenology site (mean = 0.017) compared with the arable (0.005) and horticultural sites (0.003) (Fig. 3.23). There was a highly significant ($p<0.00$) difference in the number of female *M. novaezelandiae* between the phenology site (mean = 0.145) and the horticultural (0.021) and arable sites (0.027) (Fig. 3.23).

There was a significantly ($p<0.01$) higher proportion of female *M. fasciatum* at the arable site compared with the horticultural site (Fig. 3.24). In contrast, there was no significant ($p>0.05$) difference in the proportion of female *M. fasciatum* between the arable and phenology site.

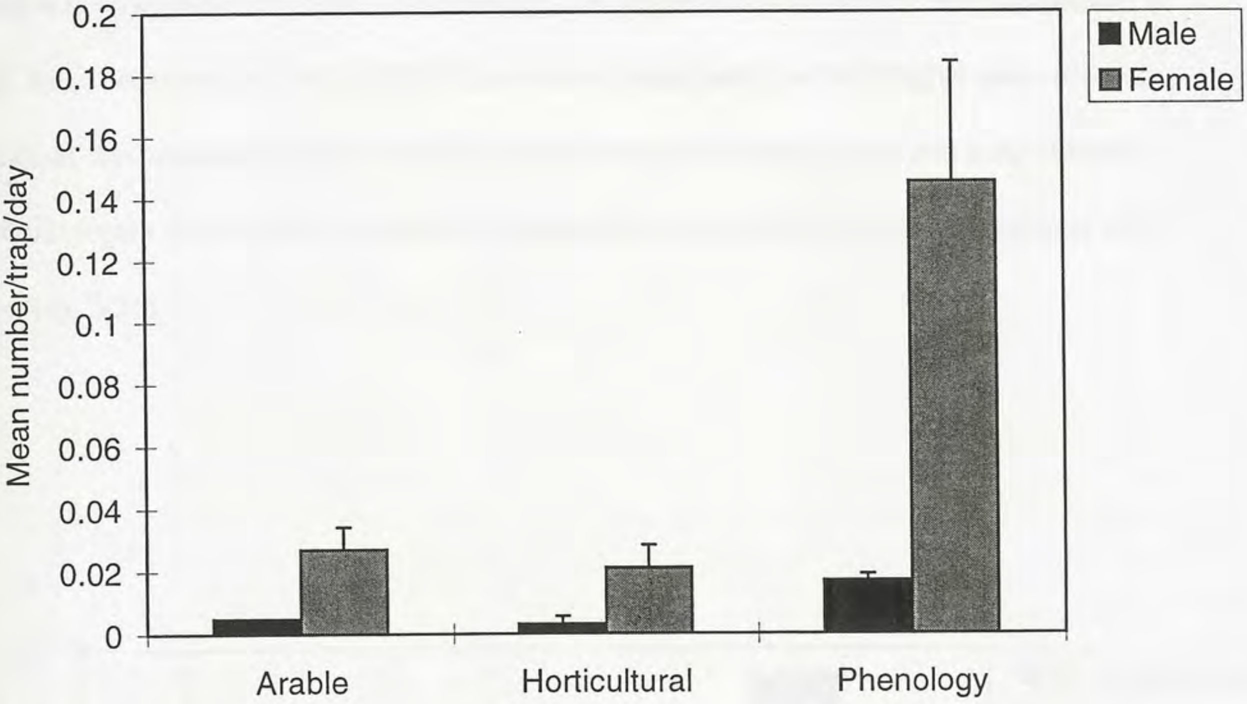

Fig. 3.23 Mean (± SE) number of male and female *M. novaezelandiae* captured at arable, phenology and horticultural sites from March 19, 1996 to May 11, 1996.

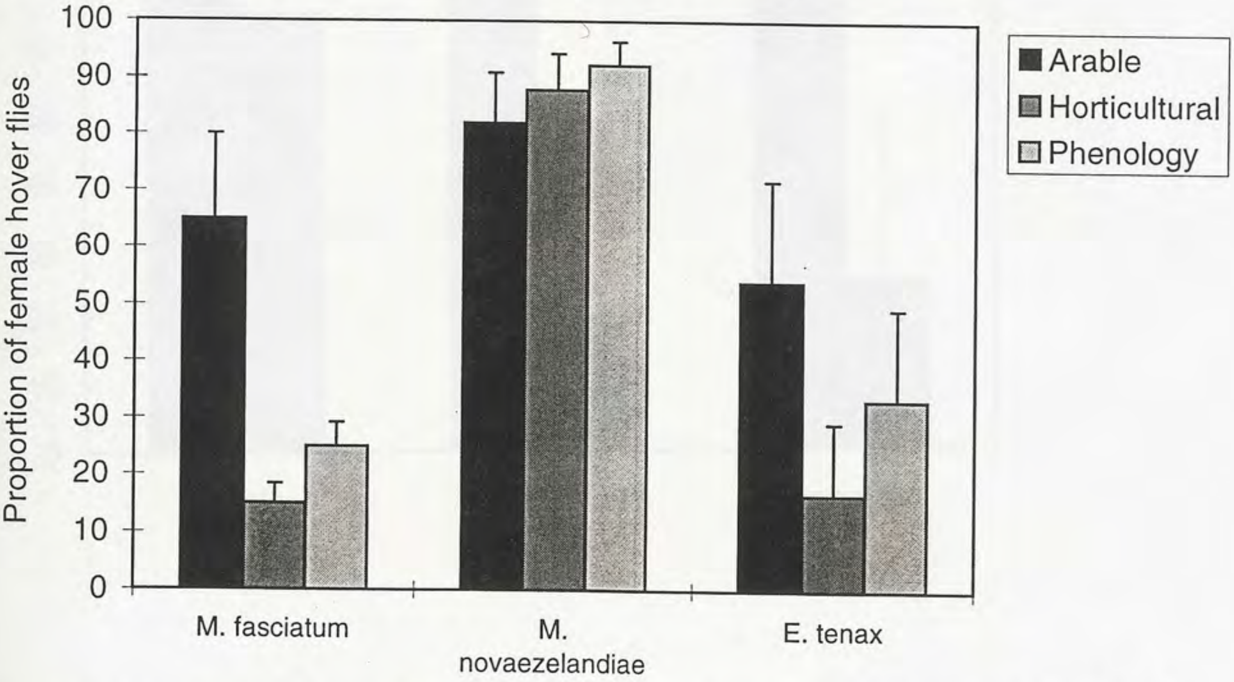

Fig. 3.24 Proportion of female hover flies at arable, phenology and horticultural sites for *E. tenax*, *M. fasciatum* and *M. novaezelandiae* from March 19, 1996 to May 11, 1996 (mean ± SE).

There was no significant ($p>0.05$) difference in the proportion of female *M. novaezelandiae* or *E. tenax* between sites (Fig. 3.24) . There was a significantly ($p<0.05$) higher proportion of female *M. novaezelandiae* than female *M. fasciatum* at all sites (Fig. 3.25) and a significantly ($p<0.01$) higher proportion of female *M. novaezelandiae* than male *M. novaezelandiae* at all sites (Fig. 3.24).

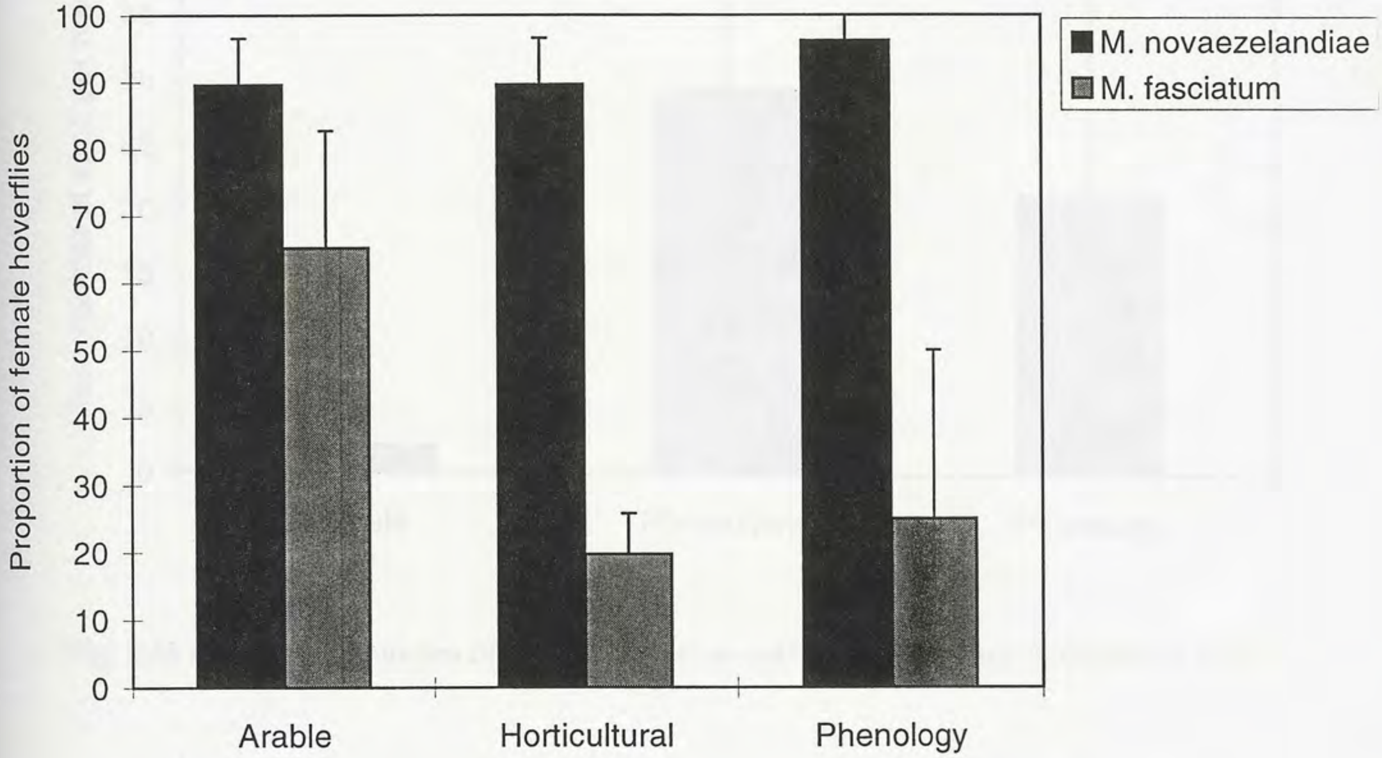

Fig. 3.25 Proportion of female *M. novaezelandiae* and *M. fasciatum* at arable, phenology and horticultural sites from March 19, 1996 to May 11, 1996 (mean ± SE).

3.2.2 Eggs

The mean number of eggs per female *E. tenax* were 29.4 at the horticultural site and 21.4 at the phenology site which was significantly ($p<0.05$) higher than the arable site (mean = 2.1) (Fig. 3.26). In contrast, there was no significant ($p>0.05$) difference in the number of eggs between sites for the other two species.

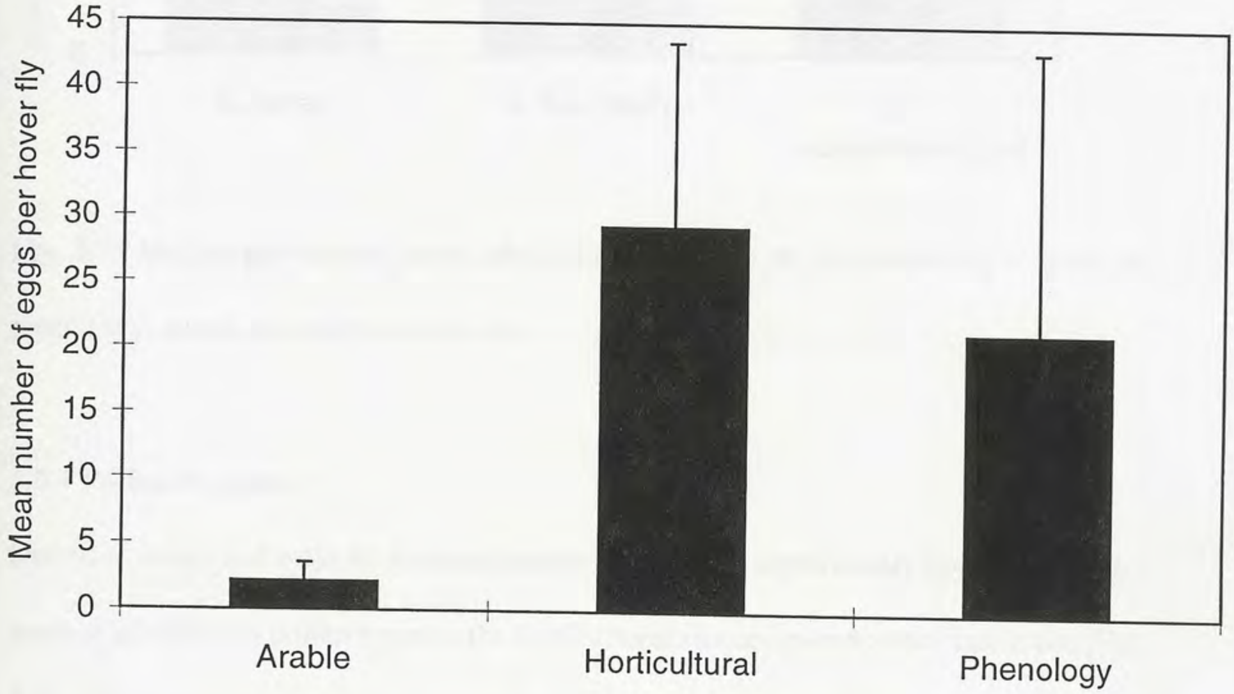

Fig. 3.26 Mean (± SE) number of eggs in *E.tenax* at arable, phenology and horticultural sites.

3.2.3 Gut fullness

Gut fullness in *E. tenax* was significantly ($p<0.05$) higher in phenology (mean = 5) and horticultural sites (6) compared with the arable site (3) (Fig. 3.27). However, gut fullness did not significantly ($p>0.05$) differ between sites for the other two species.

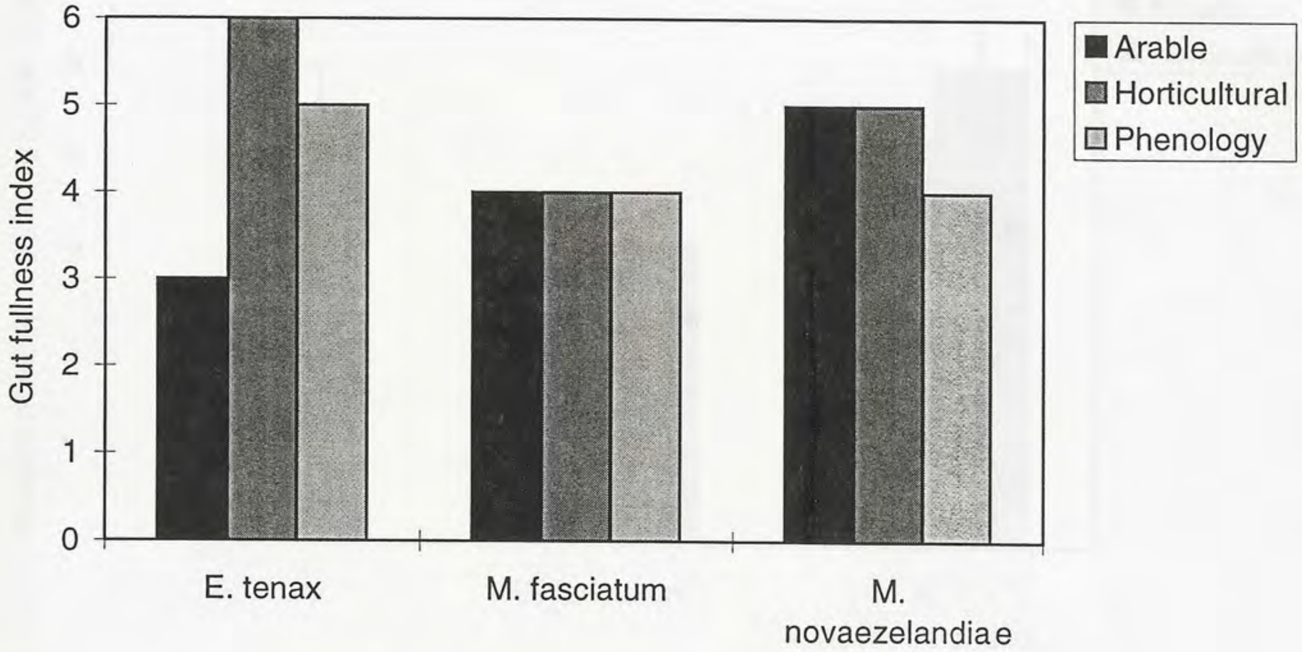

Fig. 3.27 Median gut fullness index of *M. novaezelandiae*, *M. fasciatum* and *E .tenax* at phenology, arable and horticultural sites.

3.2.4 Pollen frequency

Gravid *E. tenax* and male *M. novaezelandiae* consumed a significantly ($p<0.05$) higher number of different pollen types in the horticultural site compared to the arable site (Fig. 3.28). This same trend was consistent for gravid and non-gravid females of all species (Fig. 3.28 & 3.29). However, this was not significant ($p>0.05$). In contrast, male *E. tenax* and *M. fasciatum* consumed a lower number of different pollen types in the arable site compared with the horticultural site (Fig. 3.30) However, this was also not significant ($p>0.05$).

Pollen preference comparisons between the sites was not further explored because accurate data on the availability of pollen between sites was not available: however, histograms of these comparison are available in Appendix 2.

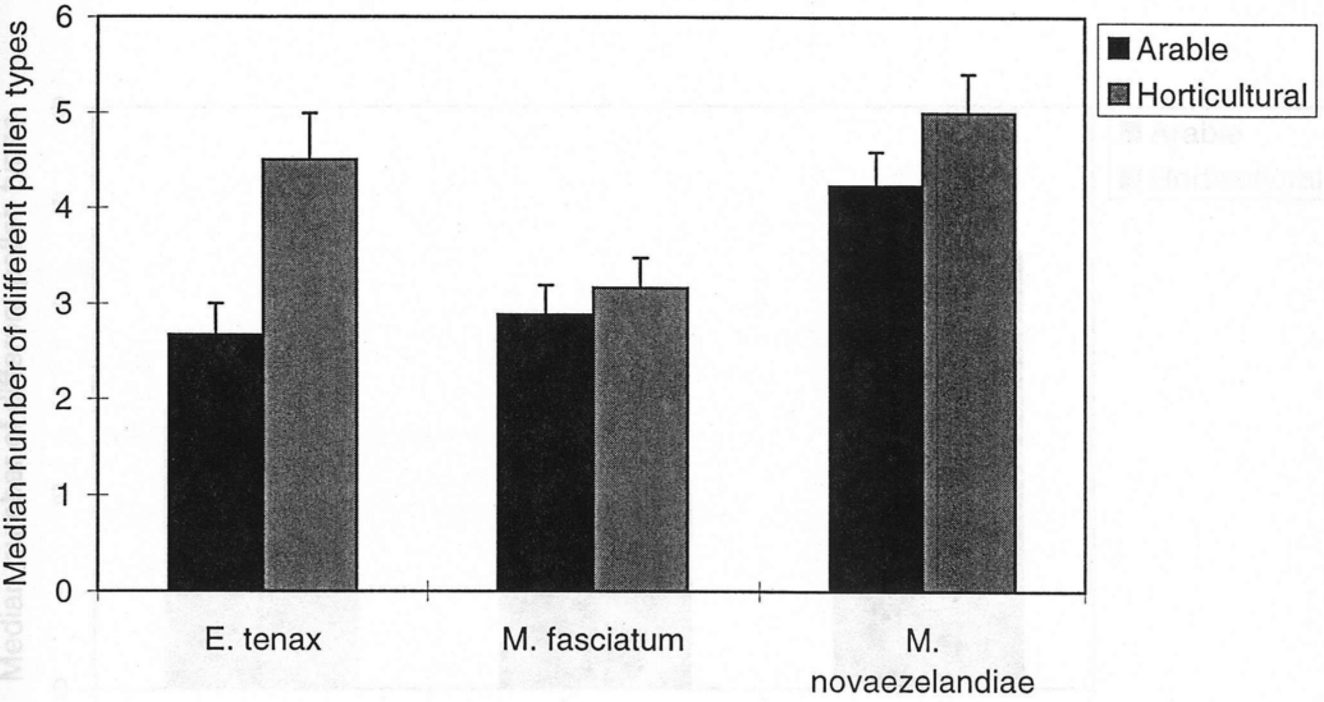

Fig. 3.28 The median (± SE) number of different pollen types in the guts of gravid *E. tenax*, *M. fasciatum* and *M. novaezelandiae* at arable and horticultural sites.

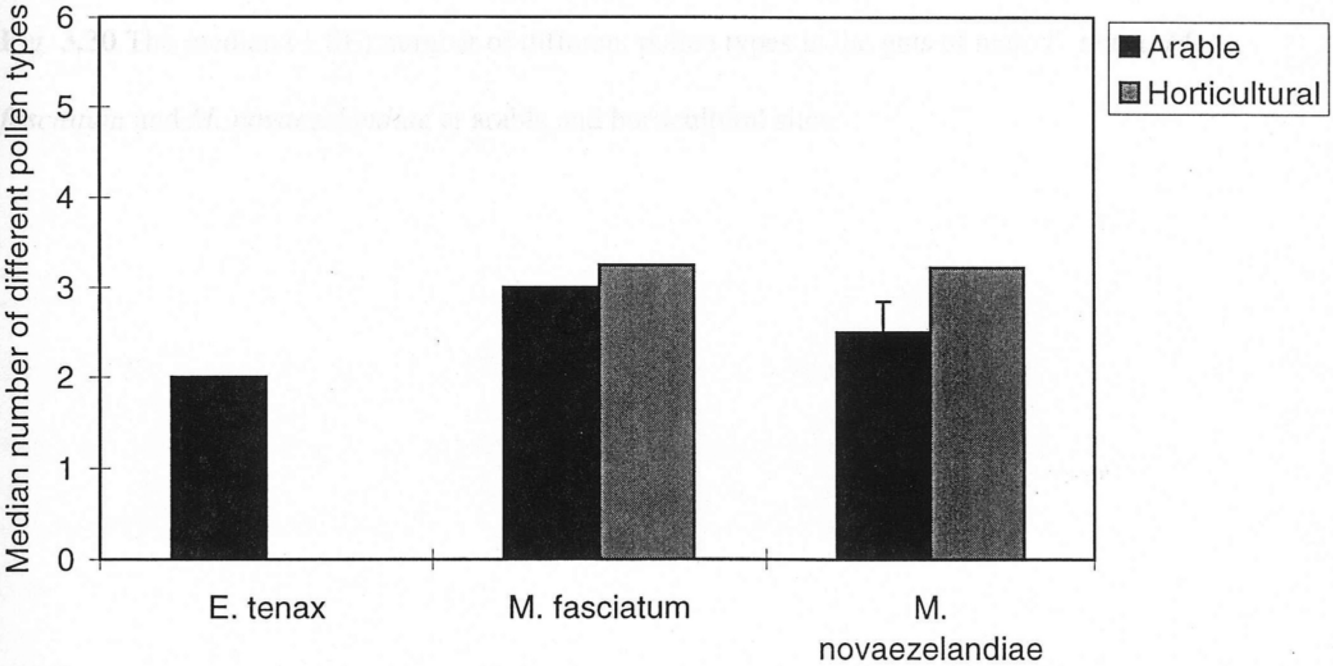

Fig. 3.29 The median (± SE) number of different pollen types in the guts of non-gravid *E. tenax*, *M. fasciatum* and *M. novaezelandiae* at arable and horticultural sites.

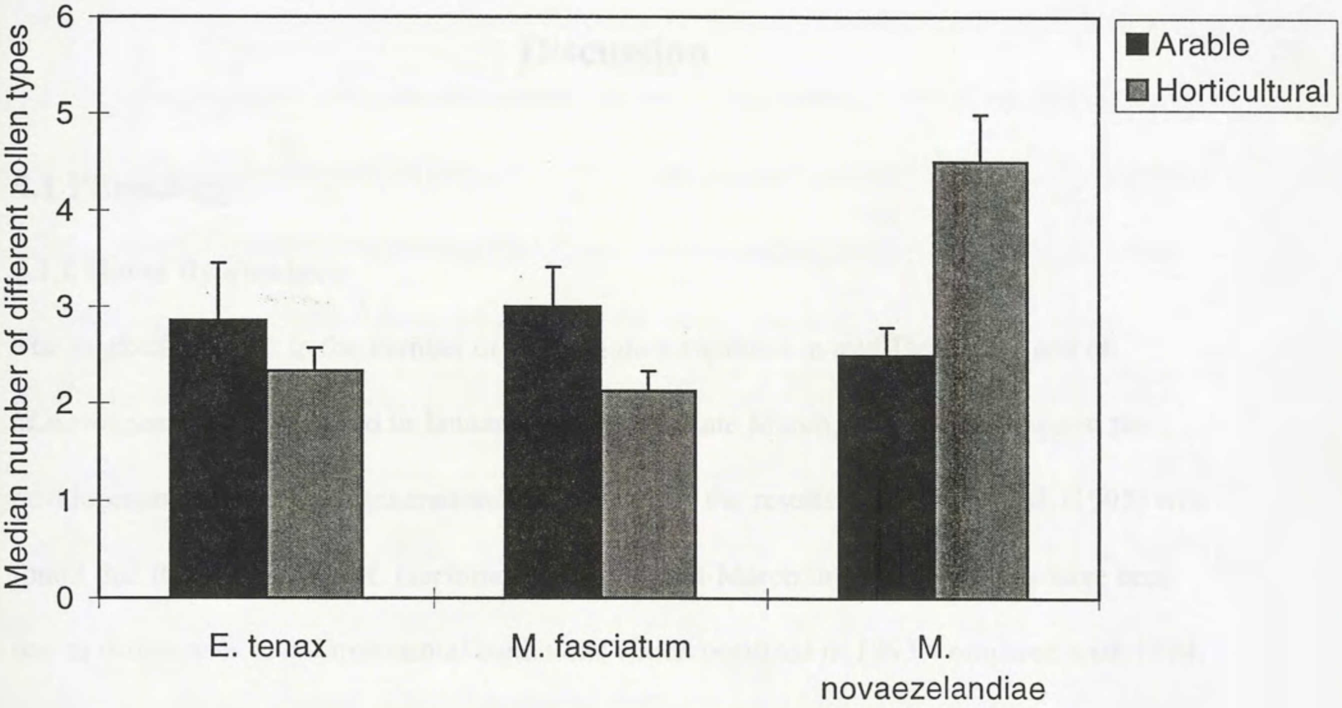

Fig. 3.30 The median (± SE) number of different pollen types in the guts of male *E. tenax*, *M. fasciatum* and *M. novaezelandiae* at arable and horticultural sites.

Chapter 4.

Discussion

4.1 Phenology

4.1.1 Hover fly numbers

The marked increase in the number of *M. fasciatum* captured in mid-December and of *M.novaezealandiae* captured in January, 1994 and in late March, 1995 would suggest the development of additional generations. This contrasts the results of Wratten *et al.* (1995) who found that the numbers of *M. fasciatum* peaked in mid-March in 1993. This may have been due to differences in environmental conditions which occurred in 1993, compared with 1994, 1995 and 1996. Furthermore, 1993 may have been a cooler season than the other years thereby delaying hover fly development and abundance until mid-March. Experimental error from variations between individuals and their operations of the traps over the years may also account for some of the difference observed between years. This makes it difficult to be confident about corresponding data between years.

The low number of aphidophagous hover flies captured before December may suggest that predation of aphids by their larvae may be limited early in the season. However, evidence from European field and modelling studies suggests that very low larval densities can still bring about large declines in aphid populations (Chambers and Adams, 1986; Entwistle and Dixon, 1989; Winder, Hirst, Carter, Wratten and Sopp, 1994).

4.1.2 Egg number and gut fullness

There was no difference in the number of eggs in females between each species; however, it would expected that the largest hover fly species (*E. tenax*) would be more capable of producing a greater number of eggs. It is also possible that the cohort of hover flies caught by the traps was not a true representative of the hover fly population in the field. *E. tenax* does not lay eggs on plants, but in stagnant water (Wratten, pers. comm.). Therefore, those female *E. tenax* with a large number of eggs present may not be caught in the traps (which represents a flower) because they are searching for stagnant water: an environment in which plants are generally not present. The trend of egg number in *M. novaezelandiae* and *M. fasciatum* throughout the year mimics the trend of gut fullness over the year (Fig. 3.4 & 3.5). This is consistent with the theory that pollen is extremely important for sexual maturation in hover flies (Schneider, 1948; Chambers, 1988) and suggests that by providing pollen sources in early spring we may be able to increase the number of eggs and larval predation during this time. In contrast to *M. novaezelandiae* and *M. fasciatum*, gut fullness in *E. tenax* was highest during the winter period. This may be due to the difference in pollen preference between the aphidophagous and non-aphidophagous species which is a result of differences in nutritional value, hover fly tongue length and flower colour (Cowgill, 1989; MacLeod, 1992). Refer to Section 4.1.3 for further elaboration on this concept. Egg number in *E. tenax* is also high during the winter period which may be due to the high degree of gut fullness or it may be due to this species laying its eggs in stagnant water: an environment which would be more prevalent during the wet winter months.

Gravid and non-gravid *M. novaezelandiae* had a higher gut fullness than male *M. novaezelandiae*; however, gut fullness did not differ between the other two species (Fig. 3.7). This may be an artefact of the low numbers of *M. fasciatum* and *E. tenax* captured during the experiment, therefore making it difficult to detect small differences in gut fullness between the genders. However, with all species combined, gut fullness was higher in gravid females than non-gravid females and male hover flies, and was higher in non-gravid female compared with male hover flies (Fig. 3.8). This is consistent with results of Hickman *et al.* (1995) and supports the theory that female flies need pollen during summer/autumn to mature their eggs, whereas males need nectar to provide energy for mate seeking. Immature females had less pollen than did gravid females because newly emerged females may take nectar for energy for mate seeking instead of eating pollen (Hickman *et al.*, 1995).

4.1.3 Pollen frequency and pollen 'preference'

Over all species of hover flies and all sites a total of 44 different pollen types was consumed. 16 different pollen types were consumed by *M. fasciatum* alone. This contradicts the results from Holloway (1976) who found that given a free choice, *M. fasciatum* fed almost exclusively on anemophilous pollen from plantain and grass families.

M. novaezelandiae consumed a larger range of pollen species in summer and autumn compared with *M. fasciatum* and *E. tenax*; whereas *M. fasciatum* consumed the least number of pollen types. This may be due to differences in the biology and ecology of the species.

All *M. novaezelandiae* genders consumed a lower range of pollen types in winter compared with all other seasons (Fig. 3.12-3.15 & 3.11). This is probably due to there being fewer flowering plant species available at this time, and to the low activity of the flies during winter as hover flies over-winter (Benestad, 1970) as adults and therefore, pollen requirements for gametogenesis would be at a minimum.

Female *M. novaezelandiae* consumed a higher number of pollen types in summer and autumn periods whereas male *M. novaezelandiae* consumed a larger range of pollen types in the spring (Fig. 3.12, 3.13 & 3.15). This suggests that oogenesis occurs during the summer and autumn and therefore, female hover flies require a larger range of pollen types during this period to obtain the various different amino acids and proteins needed for egg maturation which may not be required for normal tissue maintenance. In contrast, spermatogenesis occurs during the spring to be ready for newly emerging females, therefore, male requirements for a larger pollen range were higher during this period.

E. tenax had an opposite pollen frequency trend to *M. novaezelandiae* in that females consumed a larger range of pollen types in winter and spring; whereas, male hover flies consumed a larger range of pollen types in the summer and autumn (Fig. 3.18-3.21). This is consistent with egg maturation and gut fullness trends which were also opposite to *M. fasciatum* and *M. novaezelandiae* (Fig. 3.4 & 3.5). *E. tenax* consumed a larger range of pollen types in winter compared to *M. novaezelandiae*, including pine, *Salix* sp. and *Erica* sp. which may account for the for the higher gut fullness index of *E. tenax* in winter (Fig. 3.5).

Poaceae, Asteraceae, *Brassica*-type and Caryophyllaceae pollen types are consumed by *M. novaezelandiae* all year round indicating that they are important sources of amino acids for the diet of this species.

M. novaezelandiae was the only species to feed on *Geranium* sp., *Ribes* sp. and *Centaurea* sp.; whereas, *E. tenax* was the only species not to feed on *Phacelia* and *M. fasciatum* was the only species not to consume pine. This may be due to the differences in mouth parts between the species which would make some flower morphologies difficult to access. For example, Hickman *et al.* (1995) suggested that the reason why *M. fasciatum* may not have consumed dead nettle (*Lamium purpureum* L.) (although it was abundant) may have been because *M. fasciatum* is a short tongue hover fly (Holloway, 1976) and access to the pollen on stamens (which are hidden by a hooded upper lip) would be very difficult. Again it may also be due to differences in the biology and ecology of the species.

Gravid *M. fasciatum* was the only gender and species to consume *Rumex* sp. and then it was only taken in small quantities. This is consistent with Hickman *et al.* (1995).

M. novaezelandiae consumes *Taraxacum*-type, *Brassica*-type, Rosaceae and Asteraceae in the spring; therefore, a management option for early enhancement of hover flies may be to sow or leave these pollen sources around crop margins or in a central strip.

4.2 Comparing sites and trap efficiency

4.2.1 Hover fly numbers

Many previous studies have shown that providing increased floral diversity can increase the local densities of hover flies by providing nectar and pollen for sexual maturation (Lovei *et al.*, 1992; Sengonça and Frings, 1988; Cowgill *et al.*, 1993; Harwood *et al.*, 1994). However, in this investigation, increasing the amount of pollen in the immediate environment increased only the number of male *M. fasciatum* and did not influence the number of female *M. fasciatum*, male *E. tenax* or female *E. tenax* caught in traps. In fact, there was a higher number of male and female *M. novaezelandiae* in the phenology site which had a lower floral diversity than the horticultural site. Two explanations may account for this. First, the yellow water traps used in this investigation may be less apparent to the hover flies at the horticultural site compared with the arable and phenology sites due to the greater amount of vegetation and flowers. In fact, Hickman *et al.* (1997) discovered that a larger number of hover flies were captured in more 'easily discoverable traps' than in traps which were in more concealed positions. They also summarised that because hover flies saw traps as food, then other available food sources in the vicinity of traps compete with the traps and in turn under-estimate the number of hover flies present.

Second, the phenology and horticultural traps which were yellow-sided could be more easily seen by hover flies at a distance than the phenology traps which were green-sided and therefore the yellow part of the trap (which attracts the hover flies) could be seen only when directly above the trap, therefore a higher proportion of male and female *M. novaezelandiae* were captured at the phenology site compared to the arable and more florally diverse horticultural site. Even though *M. novaezelandiae* showed that the yellow-sided traps caught greater numbers than the green-sided traps, the different colour of the trap sides did not influence the number of *E. tenax* and *M. fasciatum* captured. This may have been because *M. novaezelandiae* makes more flights per minute, of a greater overall distance than *M. fasciatum* and because *M. novaezelandiae* is more attracted to yellow traps than *M. fasciatum* (Wratten *et al.*, 1995), both of which suggest that *M. novaezelandiae* are more likely to encounter and be attracted to the yellow-sided traps than *M. fasciatum*. It may also be due to the low numbers of *E. tenax* captured compared to the other species and to the phenology site only consisting of one replicate of five traps, therefore small differences in the numbers of hover flies captured could not be detected.

The increased number of male *M. fasciatum* found at the horticultural site (Fig. 3.22) may not only be due to the increased floral diversity present at this site but also to the greater amount of shelter provided by shelter belts and other vegetation present. There was a higher proportion of female *M. novaezelandiae* than male *M. novaezelandiae* in all sites (Fig. 3.23). This could be because the yellow trap represents an artificial flower and female hover flies are more likely to be trapped because they spend more time on flowers due to their higher requirement for pollen (as mentioned in Section 4.1.2) whereas male hover flies spend most of their time looking for females.

The accumulation of dirt, leaves and dust in the traps would have caused the traps to have been less efficient at attracting hover flies over time because they would have had decreased reflectance. This may have influenced the results gained from comparing the number of hover flies caught between each site because the amount of dirt, vegetation and other insects caught differed between each site. The number of birds present would also differ at each site, therefore the number of insects picked out of traps by birds would differ between sites. Wratten *et al.* (1995) showed that more frequent trap emptying can give higher catches of hover flies; however, during this investigation the extra labour required could not be justified.

4.2.2 Egg number and gut fullness

The median gut fullness for arable and horticultural sites were the same for *M. novaezelandiae* and *M. fasciatum* and differences between egg number for these species were not significant. This indicates that providing an increase in pollen diversity and abundance in the immediate environment does not appear to increase the amount of aphidophagous hover flies with a high degree of gut fullness. However, this does not reflect the quality of pollen in the gut in terms of the quality of the amino acid mixture, or the amount of nectar which is available at both sites and ingested for energy requirements and digestion aid. It also does not take into consideration how far the hover flies have to fly at each site to obtain the same degree of gut fullness and differences in egg numbers may not have been significant due to the low number of replicates used. Therefore, providing an increase in pollen diversity and abundance may increase the quality of amino acid mixture consumed (due to having more pollen variety for the hover flies to select the correct nutritional mixes required), increase the supply of nectar available for energy and digestion, and reduce the energy used to forage.

The number of eggs dissected from *E. tenax* was significantly higher in the horticultural and phenology sites compared with the arable site (Fig. 3.26). This may be because *E. tenax* had a higher gut fullness at the horticultural and phenology sites compared with the arable site (Fig. 3.27) and suggests that the increase in floral diversity at the horticultural site increased gut fullness and the number of eggs in *E. tenax*.

Hickman *et al.* (1997) suggested that because yellow traps represent a food source, flies with a lower gut fullness may be more likely to search out and move actively towards such traps. In this study the yellow-sided traps used at the phenology site did not capture *E. tenax* with a lower gut fullness than the green-sided traps at the arable site. However, yellow-sided traps captured *M. novaezelandiae* which had a lower gut fullness than green-sided traps which suggests that yellow-sided traps may draw a population of hover flies which are more 'hungry', rather than representing a true field population.

4.2.3. Pollen frequency

As most pollen types were plentiful in the horticultural site during the period in which this study was conducted, females could have feed exclusively on one pollen type, yet they consumed a range of several plant species. Male *E. tenax* and *M. fasciatum* consumed a lower range of pollen types at the horticultural site even though there was more variety available. This suggests that male hover flies may be more selective in what they feed on and that a fewer number of pollen types is necessary for spermatogenesis compared with female hover flies which will consume variety of different pollen types if they are available, as this range in amino acids may be necessary for oogenesis.

This experiment was constrained by the number of replicates which could be easily maintained and managed, therefore small differences in the responses of hover flies to environmental conditions could not be detected. This could have contributed to the large number of non-significant results obtained. It may be beneficial to repeat this experiment using a larger number of replicates in each site.

Chapter 5.

Summary of Main Findings

- Numbers of *M. fasciatum* reached a peak in late December-January.
- There was a peak of female *E. tenax* in early August to mid-September, whereas male *E. tenax* reached a peak in early January.
- Catches of female *M.novaezealandiae* reached a peak in mid-January, 1995 and in mid-March, 1996. In comparison, male *M.novaezealandiae* reached a peak in late December, 1994 and remained relatively low during 1995-1996.
- There was a significantly higher number of male *M. fasciatum* caught per trap at the horticultural site compared with arable and phenology sites.
- There were significantly more male *M. novaezelandiae* at the phenology site compared with the arable and horticultural sites. There were significantly more female *M. novaezelandiae* at the phenology site compared with the horticultural and arable sites.
- Gut fullness and the number of eggs in *M. novaezelandiae* and *M. fasciatum* were at their lowest during June to September, 1995. In contrast, gut fullness and the number of eggs in *E. tenax* were at their highest during June to September, 1995.
- *M. novaezelandiae* had a significantly higher gut fullness than *M. fasciatum*.
- For all species combined, gut fullness was significantly higher in gravid females compared with non-gravid and male hover flies.
- Gut fullness in *E. tenax* was significantly higher in phenology and horticultural sites compared with the arable site.

- The mean number of eggs per female *E. tenax* was significantly higher at the horticultural and phenology sites compared with the arable site.
- This research shows that increasing flower diversity in the immediate environment may enhance the abundance of hover flies, increase gut fullness and increase egg.
- *M. fasciatum* consumed fewer pollen types than did *M. novaezelandiae* and *E. tenax*.
- The number of different pollen types consumed by *M. novaezelandiae* was lower in winter compared with all other seasons for all genders.
- Male *M. novaezelandiae* consumed a higher number of different pollen types in spring compared with females which consumed a higher number of different pollen types in summer and autumn. This may indicate that spermatogenesis and oogenesis occur at different times of the year, in that spermatogenesis occurs as the new females are emerging.
- *E. tenax* consumed 15 species all year round, with males consuming a wider range of pollen types in summer and autumn and females consuming a wider range of pollen types in winter and spring. This is an opposite trend to that of *M. novaezelandiae*.
- *E. tenax* consumed a higher number of pollen types in winter compared with *M. novaezelandiae*, these pollens included *Salix* sp., *Erica* sp. and *Pinus* sp.
- Poaceae, Asteraceae, *Brassica*-type and Caryophyllaceae were used all year by *M. novaezelandiae*.
- *M. novaezelandiae* was the only species to feed on *Geranium* sp., *Ribes* sp. and *Centaurea* sp., whereas *M. fasciatum* was the only species not to feed on *Pinus* sp. Gravid female *M. fasciatum* were the only flies to feed on *Rumex* sp., and *E. tenax* did not consume *Phacelia*. This shows that species have difference pollen preferences which is possibly due to differences in mouth-parts between the species which would make some flower morphologies difficult to access.

- Gravid *E. tenax* and male *M. novaezelandiae* consumed a significantly higher number of different pollen types in the horticultural site compared with the arable site. This same trend was consistent for gravid and non-gravid females of all species. In contrast, male *E. tenax* and *M. fasciatum* consumed a significantly lower number of different pollen types in the arable site compared with the horticultural site. This suggests that male hover flies may be more selective in what they feed on and that a lower number of pollen types is necessary for spermatogenesis compared with female hover flies, which may require a larger range of pollen types to obtain the range of amino acids necessary for oogenesis.

Chapter 6.

Conclusion

This research suggests that yellow-sided traps may not be ideal for comparing populations of hover flies between areas with flowers and those without, because the flowers compete with the traps and the traps capture a cohort of hover flies which are not a true representation of the field population. The experiment also showed that by increasing floral diversity in the immediate environment, the abundance of male *M. fasciatum* can be enhanced, gut fullness in *E. tenax* can be increased and the number of eggs in *E. tenax* can be increased.

It appears that the dietary needs and the degree of gut fullness of male and female hover flies are different and this varies with season. Holloway (1976) suggested that *M. fasciatum* fed on anemophilous pollen from plantain and grass families; however, data presented here indicate that in fact, an extremely large range of flower species seem to be suitable for these species. *Polygonum* sp., Asteraceace, *Taraxacum*-type and *Brassica*-type seem to be pollens which are favourable to all species and may be good choices for enhancing hover fly abundance and their biocontrol potential. However, without laboratory testing involving determining the number of eggs produced by females reared on one pollen type or certain pollen combinations, it is impossible to say which types of pollen are best for optimum egg production or if all are equally suitable.

The extensive use of herbicides on crops and crop margins leads to lower plant diversity. By leaving crop margins or strips throughout the crop free from herbicides, or by sowing favourable pollen sources such as those mentioned above around field margins, or in central strips, the diversity of plant species can be increased. This may, in turn, enhance the abundance of hover flies, increase gut fullness, increase egg numbers and therefore perhaps increase the predation of aphids by hover fly larvae.

This research also suggests that by providing pollen from *Taraxacum*-type, *Brassica*-type, Rosaceae and Asteraceae on arable land it may be possible to achieve early-spring enhancement of aphidophagous hover fly numbers.

Chapter 7.

Future Research

Further research is required on the phenology of hover flies at other geographical locations around New Zealand, using other species of hover flies and carried out in a range of habitats e.g., orchard, other horticultural and agricultural land, native areas and conversation land. Trap colour and height for hover flies have been researched in detail in both hemispheres by Wratten *et al.* (1995), Hickman *et al.* (1997) and Mackie (1996); however, additional research may be required to compare populations captured by different trapping techniques, such as sticky traps versus water traps.

White *et al.* (1995) and Evans (1996) are the only studies which have investigated the potential of hover flies as biological control agents in New Zealand, both on *Brassicas*. Therefore, additional work is required to assess the biocontrol potential of hover flies in New Zealand for other aphid-susceptible crops and to find out if the use of increased floral diversity is a management option that is likely to lead to a reduction in aphid populations. An essential aspect for future research on the potential of hover flies at biocontrol of aphids is to determine whether hover fly enhancement can reduce aphid populations below economic thresholds and whether they may save farmers money, in terms of reducing pesticide usage. The potential of enhancing hover flies for biological control could also be investigated for pest species other than aphids, for example, lepidopteran pests in orchards.

In all future experiments which use traps to capture hover flies, the type of trap used needs to be considered, so that the cohort of hover flies captured is the part of the overall population which is required to be monitored. For example, when comparing sites with and without flowers, yellow-sided yellow water traps may not give a good representation of the population of female hover flies captured due to the flowers' competing with traps and reducing numbers captured in traps. When demonstrating the potential of hover flies as biological control agents, it is also important to consider the ideal methodology. White *et al.* (1995) showed that planting *Phacelia* around *Brassica* field increased hover fly egg numbers laid and reduced aphid populations. However, this was not reflected in the number of gravid female hover flies captured. In future work it may be more beneficial to have green traps placed on the ground, in addition to yellow traps on sticks, so that gravid females are also captured (gravid females are attracted to green traps because they are looking for plants to lay their eggs). When comparing differences in hover fly numbers between bare ground and a more vegetation-rich site, yellow-sided yellow water traps may bias results because traps will be more conspicuous at sites with low vegetation and will in turn attract a larger population of hover flies. It therefore may be beneficial to have green-sided yellow water traps so that at both sites hover flies can detect the yellow part of the trap only if they are directly above it. Finally, further research is required on the phenology of and the effect of trap colour, trap type and trap height on other natural enemies, such as parasitoids and additional investigations are necessary to determine the potential of enhancing these natural enemies for biocontrol of pest populations in New Zealand.

Chapter 8.

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I wish to thank my supervisor, Dr. Steve Wratten, whose guidance throughout this year has been truly invaluable. A big thank you to Bruce Chapman for his helpful advice and comments on an early draft. Thanks to Chris Frampton and Graham Hickling for their much needed and deeply appreciated statistical assistance. I would also like to thank A. Evans and A. Allen for collecting some of the phenology data and F. Farmer for assistance in dissection. Thank you to Neville Moar for all his invaluable help with pollen analysis, for this I am truly grateful. Thanks also go to everybody in the Department of Entomology and Animal Ecology for their help and the many Thursday nights of entertainment at 'Bobs' throughout the year.

I'd like to thank Mel Haines for helping pretend that everything was under control, and to Blakie, it was great to know that we were in this nightmare together. A big thanks to my flatmates, Marco and Nick, the best flatmates a gal could ever dream of, whom without them this year would have been a lot more organised and productive, but so much less exciting, F4E guys! Thanks to my good friend Keenz for understanding and never failing to be there.

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Chapter 8.

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Chapter 9.

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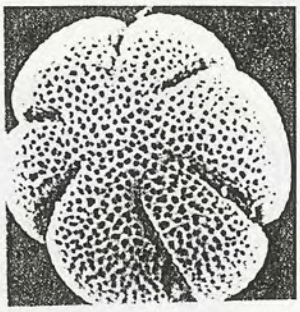
Appendix 1. Pollen guide to the identification of pollen types found in *E. tenax*, *M. fasciatum* and *M. novaezelandiae*.

Arailaceae:

- triangular
- 3 pores
- spikey

Labiatae:

- zonocolpate
- foot ball-like
- 6-sided



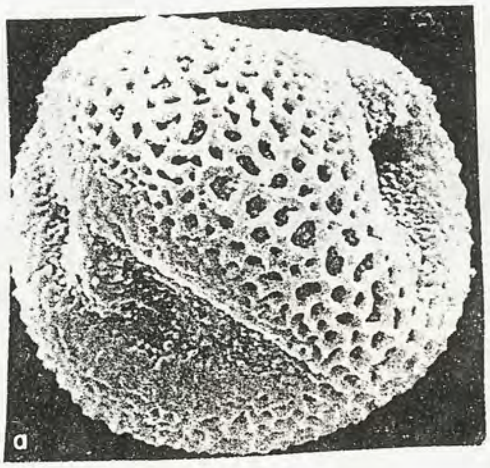
Sedum:

- trizonocolporate
- rugulae straight and long

Salix:

- 3-sided
- edges of colpi usually inrolled
- exine thickness decrease towards the colpus
- granular or stipled

eg: willow



Centaurea:

- obtuse triangular prism shape
- pori present
- granular

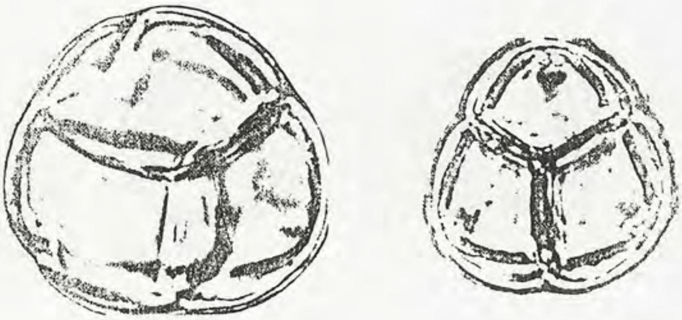
Tilia:

- very distinctive
- large grain
- exactly like picture

eg: lemon

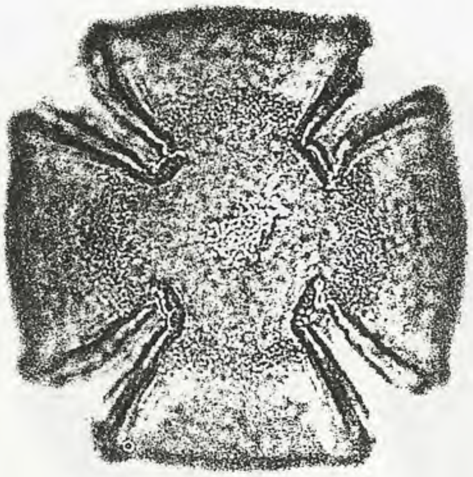
Erica:

- extremely large grain
- three compartments
- bubble-like



Viola:

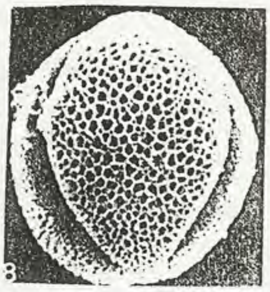
- large
- can be zonocolpoate
- leaky
- can be 3-sided
- many types

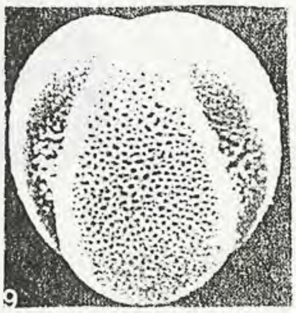


Scrophulaceae:

- thickish wall
- exine remains roughly the same thickness from mesocolpia to poles
- variable

eg: veronica

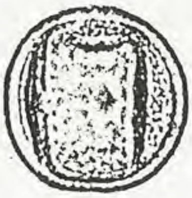




Rumex:

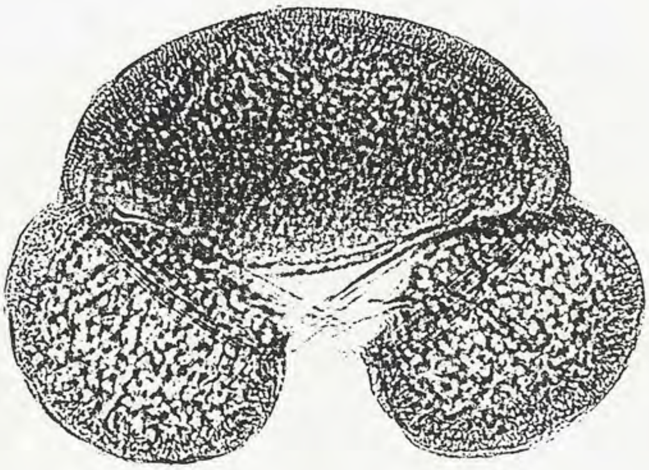
- rounded with four semi-circles in side

eg: dock



Pine:

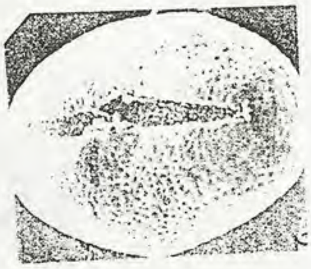
- extremely large
- lightly stained
- croissant-like
- crab-like



Fabaceae:

- elongated
- large umbel type
- large, long furrow

eg: pea, bean



Ranunculus:

- spines like -
- rounded
- colpi wide and coarsely granulated
- exine sometimes thicker along the colpus margins

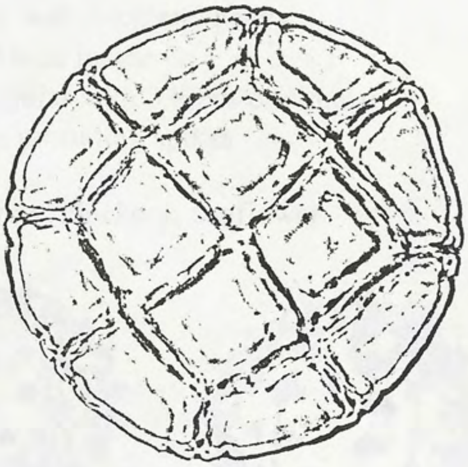
eg: buttercup

Phacelia:

- basket ball like
- striped
- rounded balls

Acacia:

- large grain
- cross hatch
- grenade-like

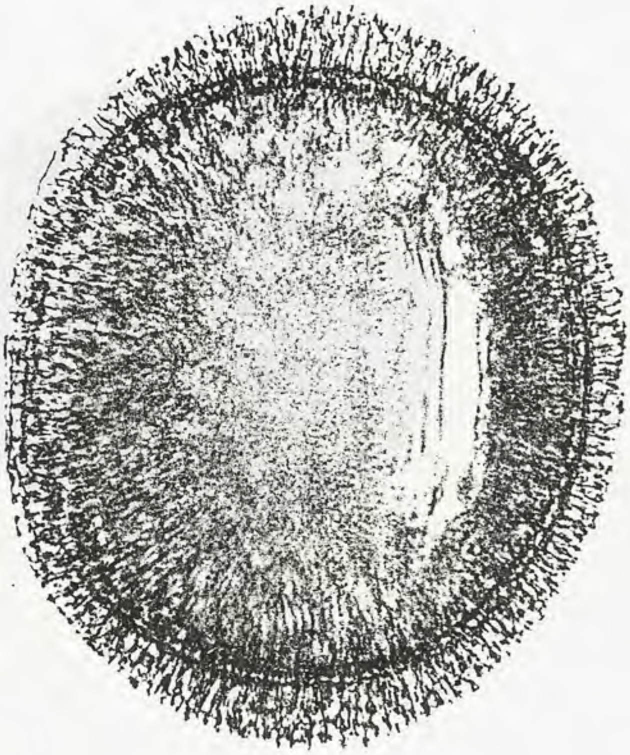


Veroncia:

- small grain
- membrane granular
- rounded

Erodium:

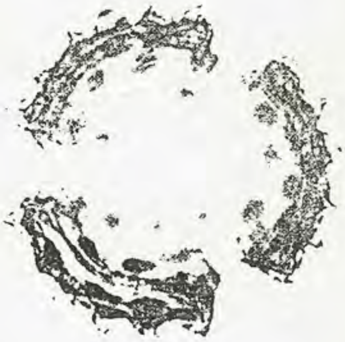
- very large grain
- thick and coarse walls
- 3 lobed with three pores



Asteraceae:

- outer wall thick and heavy
- bold rods inside
- triangular with 3 lobes or circular
- large protuding spikes

eg: yarrow, chickory, sunflower



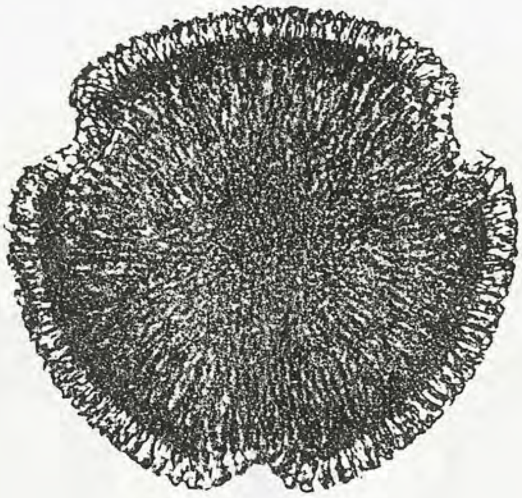
Taraxcum:

- lacey
- exire ridges, thick
- spines small

eg: dandelion, sow thistle

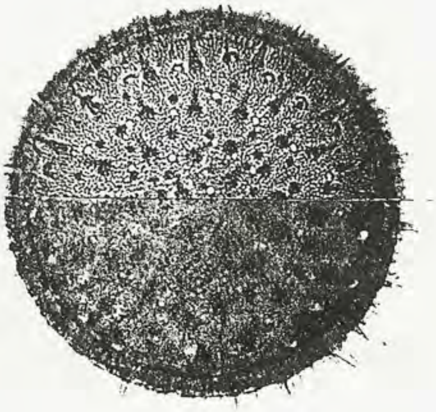
Scabiosa:

- very large
- rounded to oval
- extremely thick wall
- densely packed over grain surface
- stains brown/dark



Malvaceae:

- very large conker type
- spikey
- circular
- short acute supratectal spines



Galium:

- 5-6 lobed
- light pink stain
- subprolate, flattened at poles
- sometimes markedly lobed

Brassica:

- rounded triangle ends
- three pores
- many difference forms

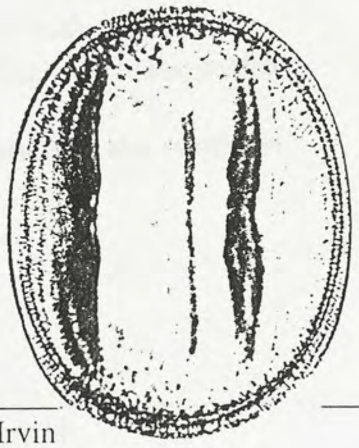



Roseaceae:

- triangular
- slighly rounded at poles
- striate

Polygonum:

- large umbel-like
- ablong
- peripolate
- thick wall



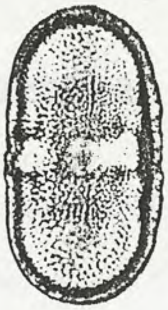
Caryophylaceae:

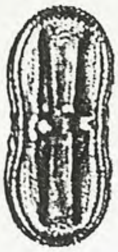
- golf ball like
- not as many pores as Chenopodiaceae
- thick wall
- smooth granular spikes

Umbelliferaceae:

- oblong
- furrow running along top with pole at each end

eg: carrot





Motaceae:

- triangular
- three pores
- light pink stained
- triangle bit in the centre

eg: manuka, rata, eucalptus

Poaceae:

- one pore
- round, smooth
- granular inside
- damage easily therefore may be broken up/distorted

eg: grasses and mazes

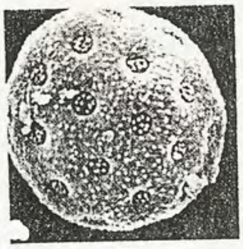
Plantago:

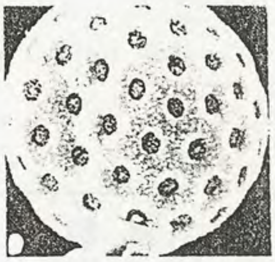
- pores 3 + but fewer than caryophillaceae and chenopodiaceae
- a lot like grass
- spheroidal to oval
- can be broken up/distorted
- rim presence around pores
- granular
- verrucate

Chenopodiaceae:

- golf ball like
- many pores (40-70) regularly arranged.

eg: fat hen, spinach





Appendix 2. Pollen preference comparisons between arable and horticultural sites for each hover fly species and gender.

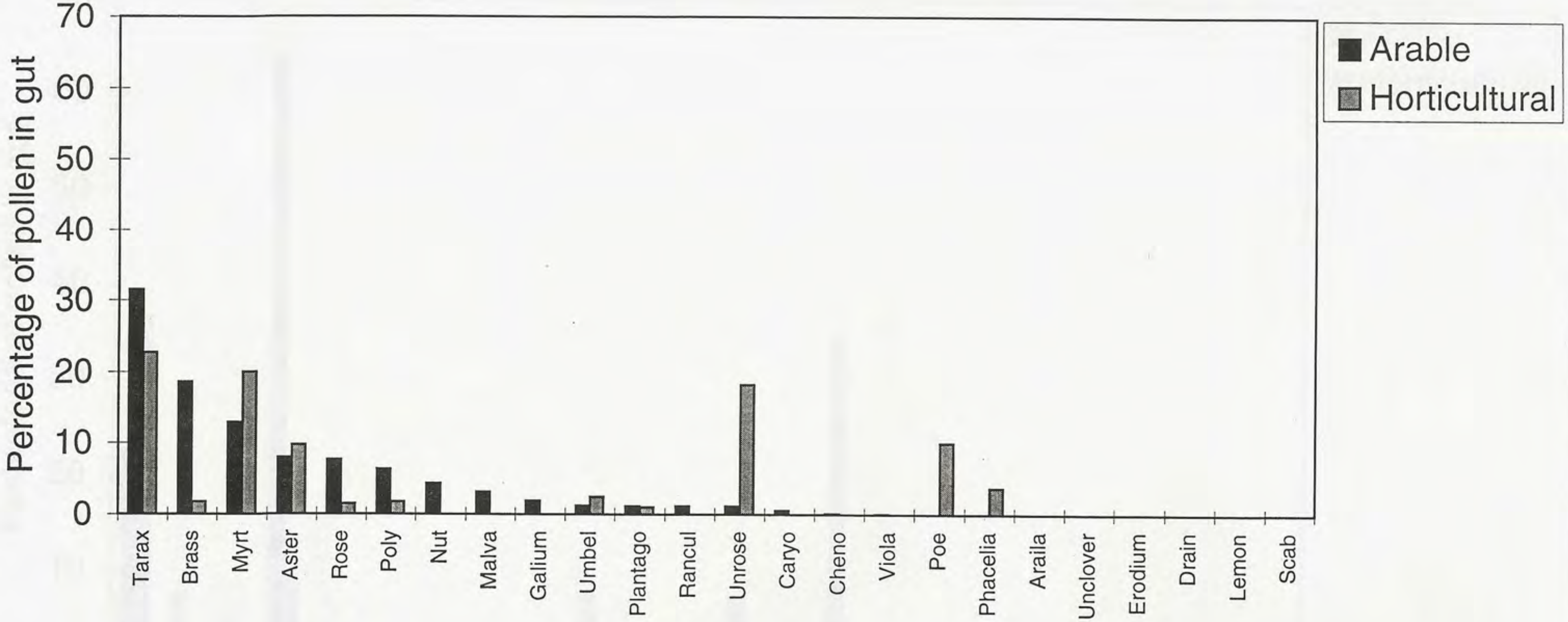


Fig. 1 Percentage of pollen types in the guts of gravid *M. novaezelandiae* at arable and horticultural sites (Tarax = *Taraxacum*; Brass = Brassica type; Myrt = Myrtaceae; Aster = Asteraceae; Rose = Rosaceae; Poly = *Polygonum* sp.; Nut = Nut type; Malva = Malvaceae; Galium = *Galium* sp.; Umbel = Umbelliferae; Plantago = *Plantago* sp.; Rancul = Ranuculaceae; Unrose = unknown Rosaceae type; Caryo = Caryophyllaceae; Viola = *Viola* sp.; Poe = Poaceae; Phacelia = *Phacelia tanacetifolia*; Araila = Arailaceae; Unclover = unknown clover type; Erodium = *Erodium* sp.; Drain = *Geranium* sp.; Lemon = unknown lemon type; Scab = *Scabiosa* sp.).

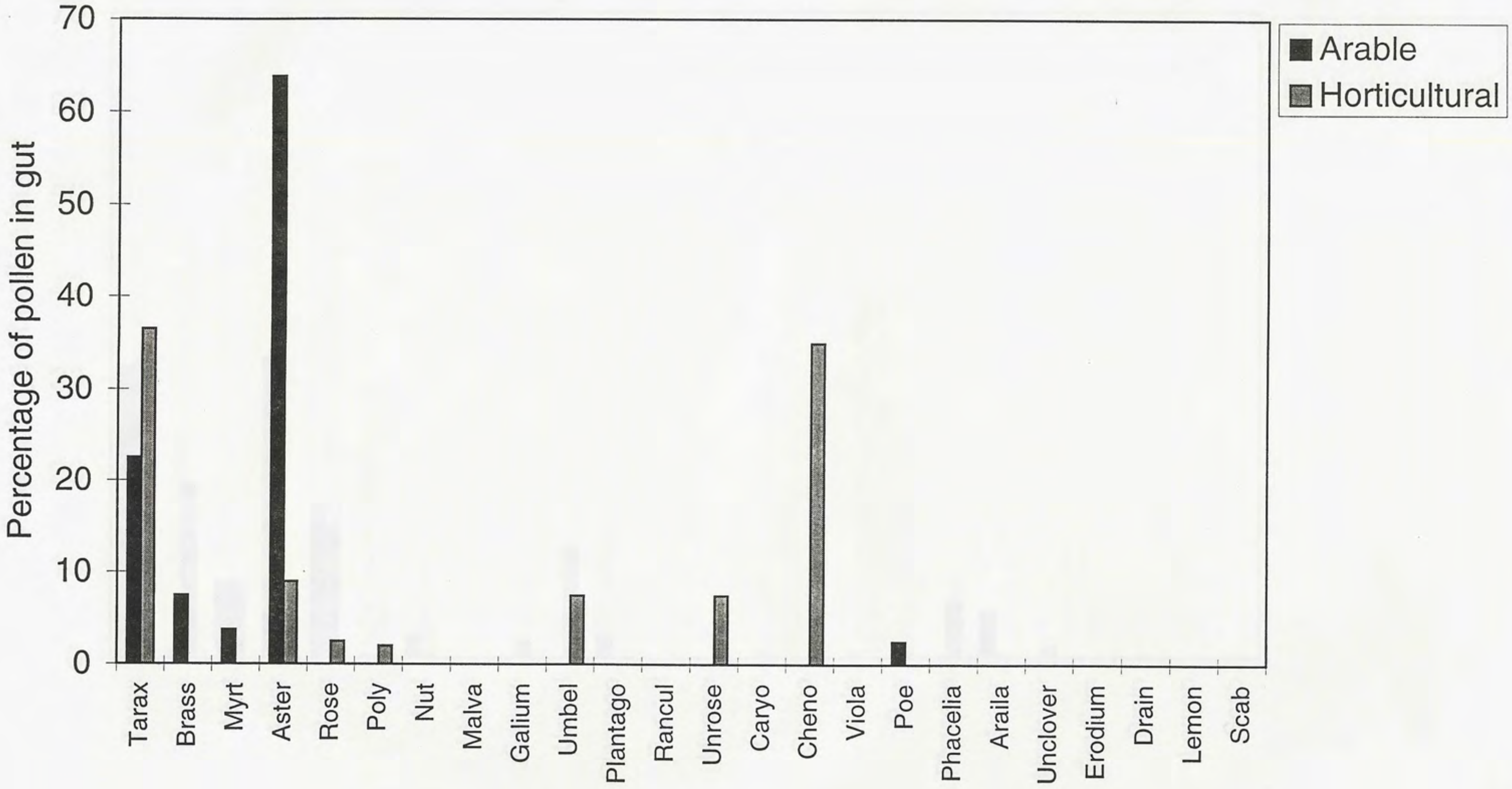


Fig. 2 Percentage of pollen types in the guts of male *M. novaezelandiae* at arable and horticultural sites (refer to Fig. 1).

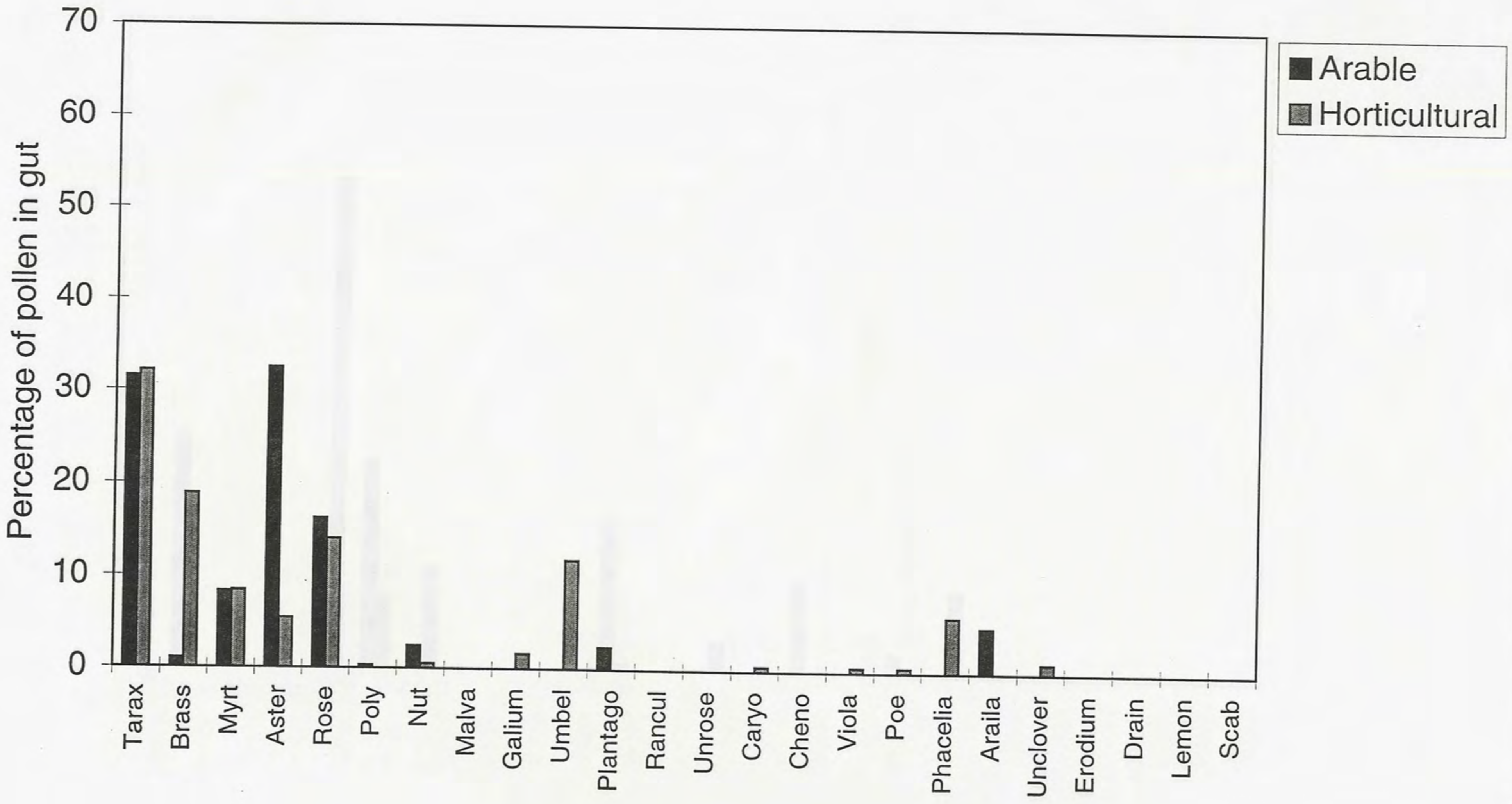


Fig. 3 Percentage of pollen types in the guts of non-gravid *M. novaezelandiae* at arable and horticultural sites (refer to Fig. 1).

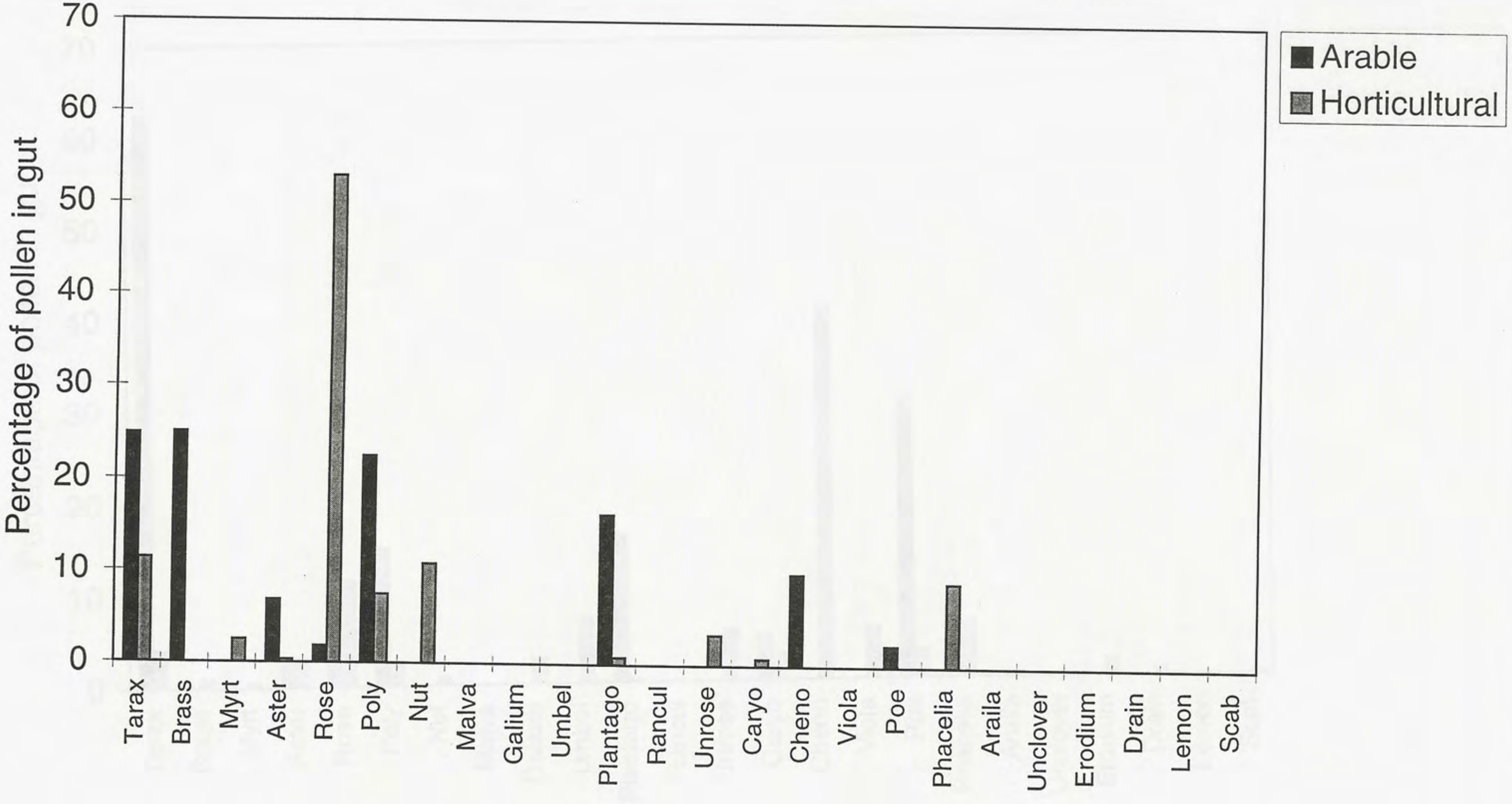


Fig. 4 Percentage of pollen types in the guts of gravid *M. fasciatum* at arable and horticultural sites (refer to Fig. 1).

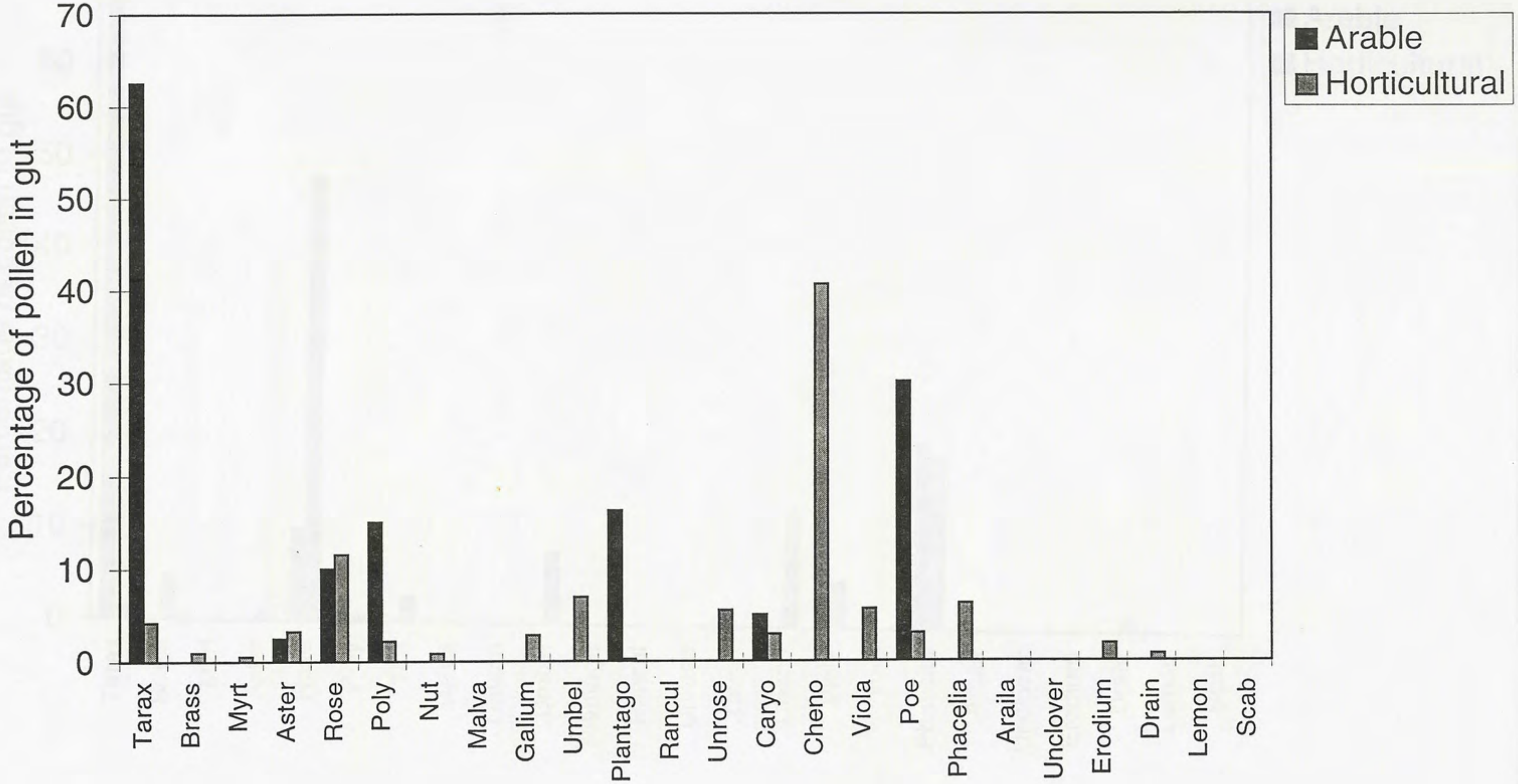


Fig. 5 Percentage of pollen types in the guts of male *M. fasciatum* at arable and horticultural sites (refer to Fig. 1).

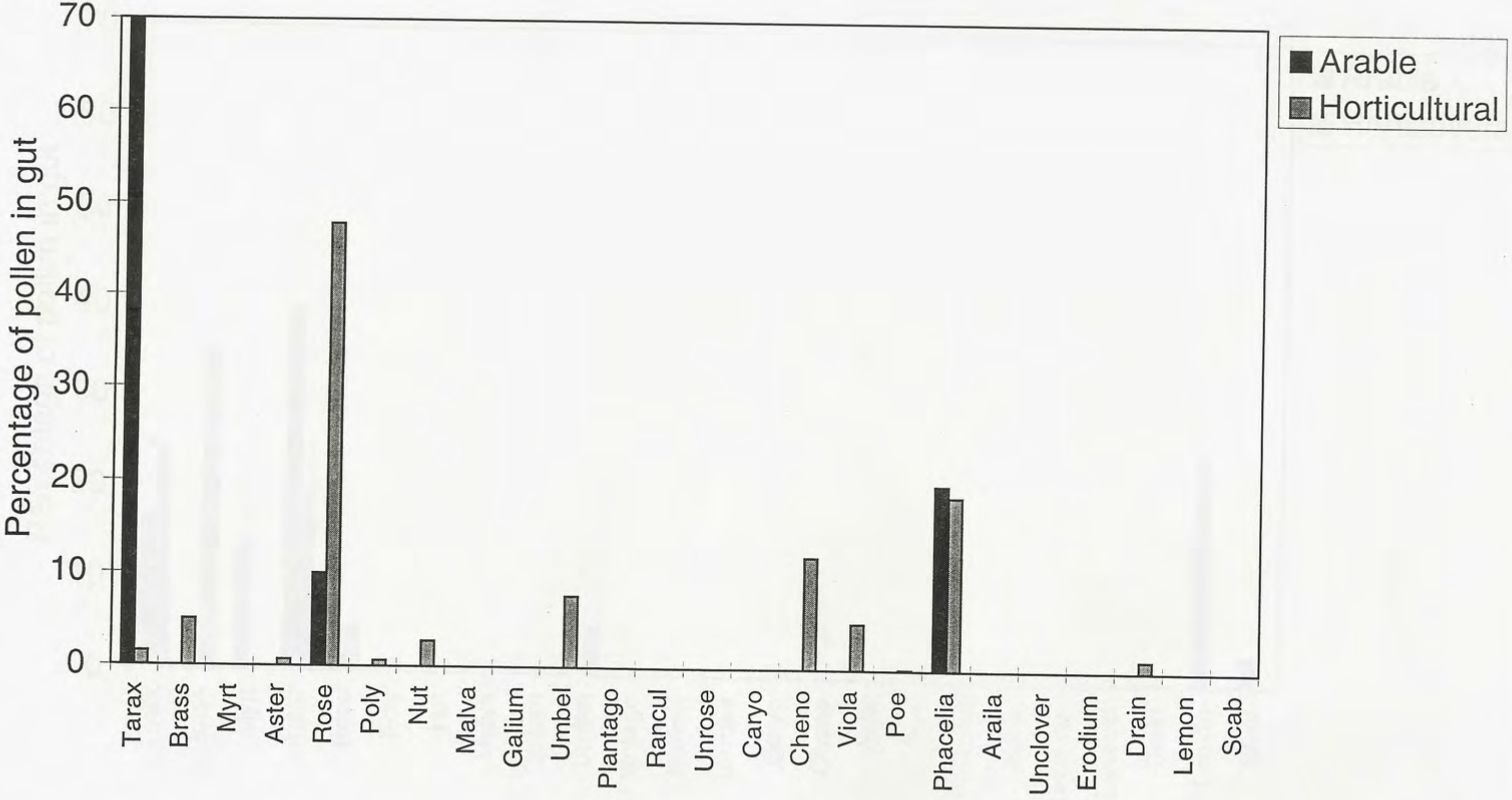


Fig. 6 Percentage of pollen types in the guts of non-gravid *M. fasciatum* at arable and horticultural sites (refer to Fig. 1).

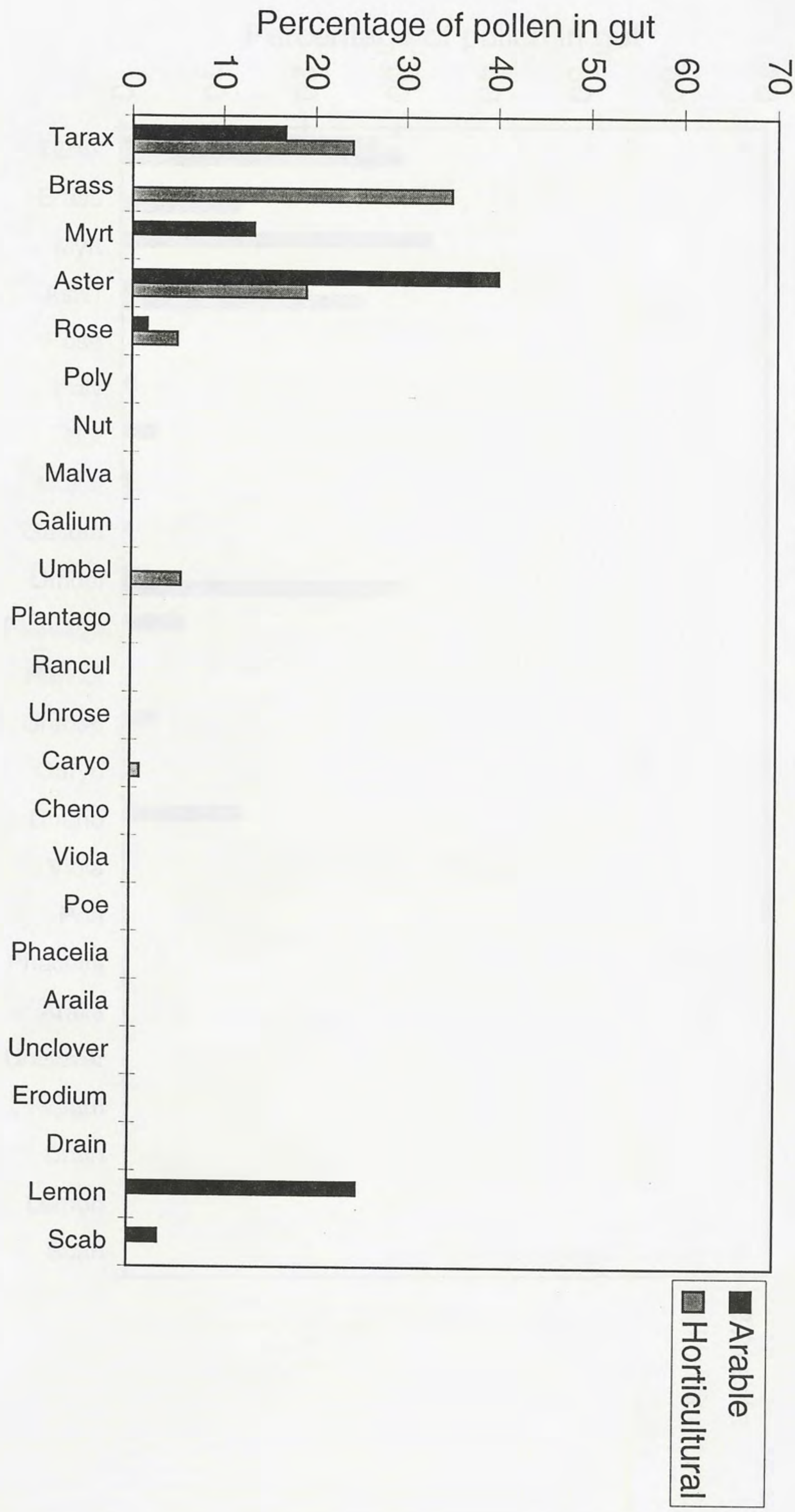


Fig. 7 Percentage of pollen types in the guts of gravid *E. tenax* at arable and horticultural sites (refer to Fig. 1).

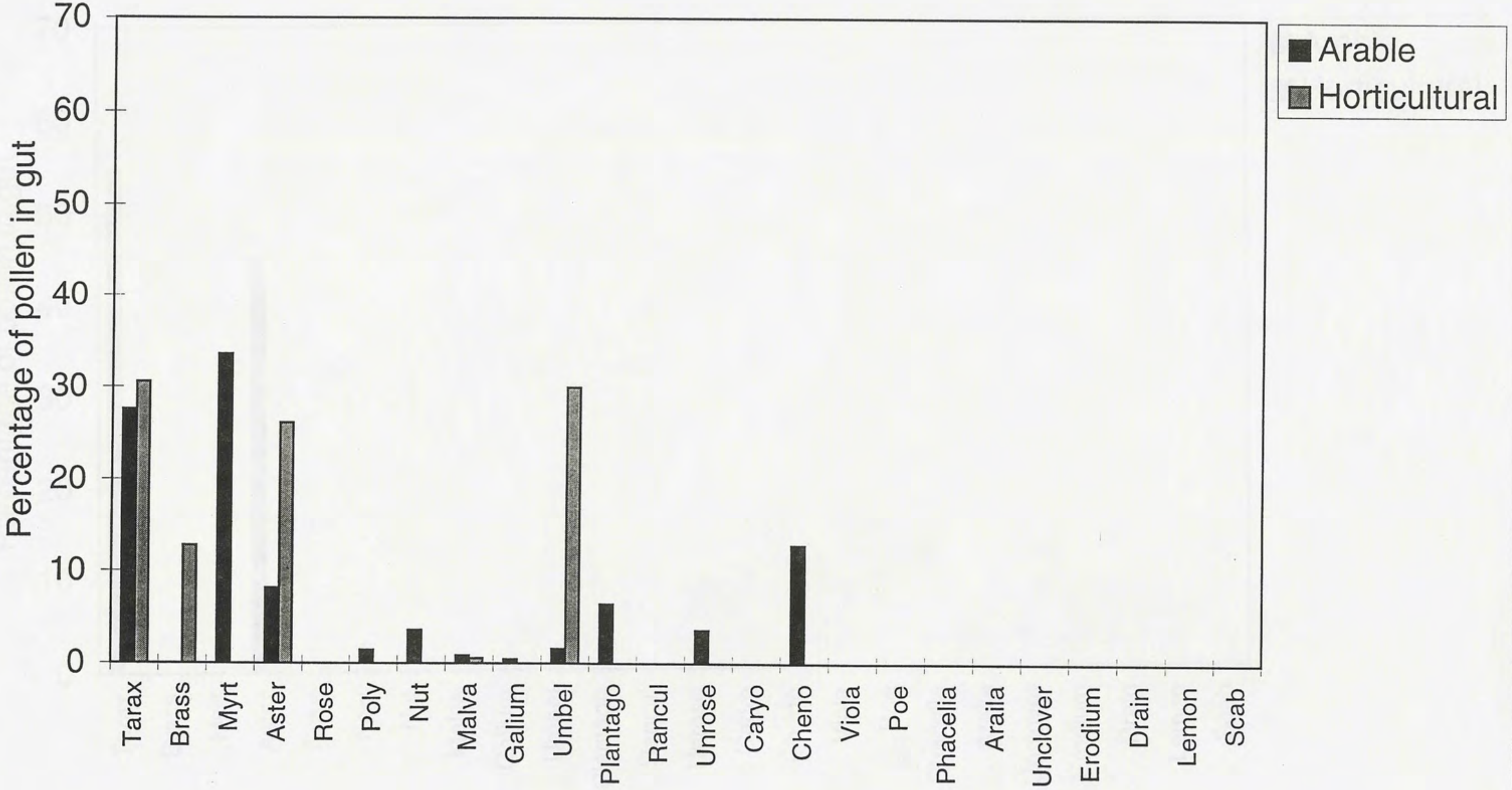


Fig. 8 Percentage of pollen types in the guts of male *E. tenax* at arable and horticultural sites (refer to Fig. 1).

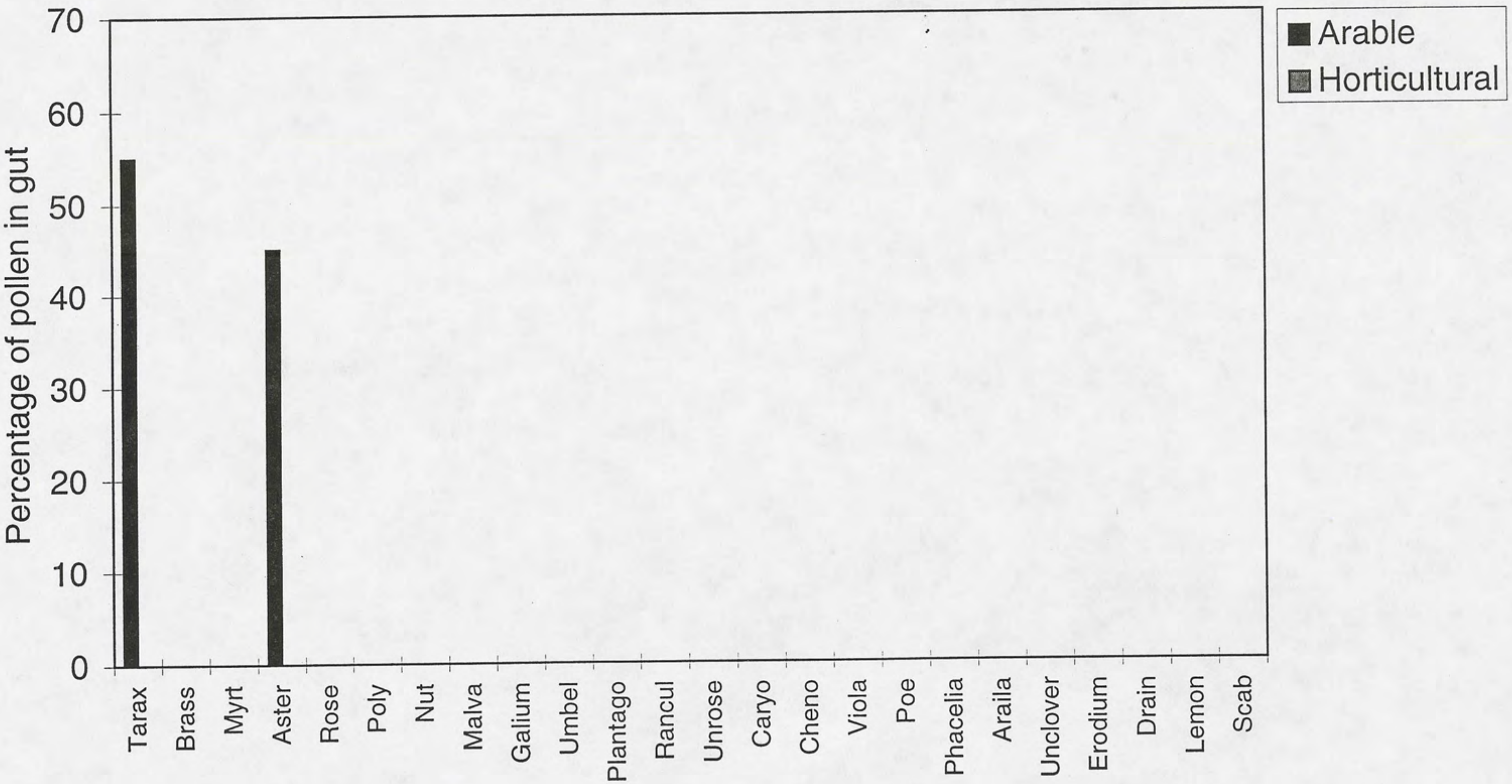


Fig. 9 Percentage of pollen types in the guts of non-gravid *E. tenax* at arable and horticultural sites (refer to Fig. 1).