# Arthropod natural enemies in stored products – overlooked and under-exploited

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*Abstract*

Three decades ago, it was widely assumed that contact insecticides and fumigants would continue to provide a panacea for storage pest control for the foreseeable future: pest resistance would be overcome by rotation of compounds and replacement by new pesticide generations; and environmental concerns were not seen as relevant to well-targeted applications in food stores. Thirty years on: resistance is widespread; efficacy claiming for surface treatments have been challenged; there is no new generation of conventional pesticides; the choice of fumigants is currently narrowing from two to one; and consumers globally are demanding minimal or zero tolerance of pesticides in food

Over this period, published research on biorational and environmentally sustainable alternatives to conventional pesticides has increased, from a trickle of studies on natural enemies, pheromones, hermetic systems and inert dusts, to a wealth of research on botanical toxins or repellents, controlled atmospheres or alternative fumigants, growth regulators and activated dusts A key feature of the increased research on alternatives is that it has been predominantly concerned with additives, whether solid, liquid or gaseous: such alternatives are therefore potentially susceptible to the same problems of pest resistance or consumer rejection as conventional pesticides. By contrast, research and innovation on ecologically-based alternatives have been characterized by two decades of moderate growth followed by stagnation and, indeed, some recession in the third decade. The total numbers of references to arthropod predators and parasites of storage pests increased steadily from the early 1970s to the late 1980s, but have since levelled off and slightly decreased through the 1990s. Most of these references do not report field observations of natural enemies in food storage, and many relate merely to mass-rearing of predators or parasites on storage pests as convenient laboratory hosts or prey: indeed, a surge of publications on such mass-rearing accounts for most of the apparent increase in research on natural enemies of storage pests in the 1980s.

This paper discusses the possible reasons why the potential for biological control by natural enemies has been largely overlooked in practical storage pest management, with a few exceptions, in spite of the increasing pressure to find safe and sustainable alternatives to conventional pesticides. A key factor is the paucity of basic information on the occurrence, biodiversity and ecology of arthropod natural enemies in food storage This is illustrated by a comparison of the range of predators and parasites found in a survey of Indonesian food stores with the published information on their distribution and ecology.

## Background and Challenge

Three decades ago, following the major mid-century advances in synthetic chemistry, it was widely assumed by many that prophylaxis with contact-insecticide grain protectants and disinfestation with a variety of fumigants would continue to provide a panacea for storage pest control for the foreseeable future (Haines 1998). In spite of the early evidence of resistance of mosquitoes to DDT and the warnings of environmental pollution first publicly articulated in the book 'Silent Spring' (Carson 1962), this confident vision persisted into the 1970s. In the late 1960s, it was still believed that the emerging pest resistance to organophosphorus compounds would be overcome by alternating the use of different compounds and, indeed, by their replacement with new generations of synthetic pesticides. The wider environmental impacts of these pesticides, much publicized by Carson and others, were also not seen as relevant to the low-dosage well-targeted applications of less toxic pesticides in food stores.

Thirty years on – and with the benefit of hindsight – we know that this confident vision was unjustified. Resistance to pesticides is now widespread and affects all families of synthetic compounds. The long-held claims that surface treatments of bag-stacks and store surfaces with contact insecticides are efficacious have been challenged and, under tropical conditions at least, disproved (Gudrups et al. 1994). The so-called 'fifth generation' of conventional pesticides, which it was predicted would follow the synthetic pyrethroids, has failed to materialize. The choice of commercially available fumigants has narrowed to just two, of which one (methyl bromide) is being phased out by

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international agreement due to its role in ozone depletion (Taylor 1994), and the other (phosphine) is being constrained by development of pest resistance (Taylor 1989). And finally, irrespective of these technical issues of efficacy, consumers globally are increasingly concerned about the hazards of synthetic pesticide use, whether related to operator exposure, environmental contamination or (most importantly) chronic effects on consumer's health, and are demanding minimal or zero tolerance of these pesticides in food.

## Alternatives to conventional pesticides

There has thus been a steady increase in demand for cost-effective safe alternatives to the conventional synthetic insecticides used in food storage systems, and it is now widely recognized that the future of storage pest management lies in biorational and environmentally-sustainable control measures in integrated pest management systems. The change of emphasis is evident in the changing balance of focus of scientific publications in recent decades. In the 1960s, there was little more than a trickle of studies on natural enemies, pheromones, hermetic systems and inert dusts, compared with the great number of papers describing trials of the efficacy and application of synthetic insecticides. In the late 1990s, by contrast, there is a wealth of research being published on botanical toxins or repellents, controlled atmospheres (CA) or alternative fumigants, insect growth regulators (IGRs) and activated dusts. The increasing interest in these alternatives is well illustrated by the work on neem. A literature search for publications on the use of neem against storage pests reveals a total of 202 such references in the past three decades. As are shown in Figure 1, the numbers of such references have been rising steadily from less than one per year in the 1970s to over 15 a year in the mid-1990s, with an abnormal peak in 1987 caused by the publication of the proceedings of an International Neem Conference, and with as yet incomplete data for 1997.

Similar growth has occurred in research on the other approaches noted above: other botanicals, controlled atmospheres, growth regulators and dusts. The first of these, in particular, is becoming the dominant area of research on storage pest management. Unfortunately, such research is not always conducted and disseminated uncritically In an eagerness to promote safe alternatives to discredited synthetic chemicals, proponents of the use of botanicals often claim that they are, *a priori*, safe because they are natural products, whereas some of the substances being tested are already known to be toxic to humans, as noted by Haines (1998). A key common feature of the rapidly increasing research on alternative methods is that the growth areas are predominantly concerned with additives, whether solid (admixed dusts and raw botanicals), liquid (dust slurries, IGR formulations, oils and botanical extracts) or gaseous (CA and new fumigants).

Pragmatically, this focus on additives is easy to understand: by comparison with existing systems dependent on application of synthetic contact insecticides and fumigants, it represents a ‘least-change’ option both conceptually and practically In principle, the focus is more difficult to justify as a real alternative to the problems of synthetic pesticides. The modes of action of these alternative additives are broadly the same as the conventional pesticides they are intended to replace One problem has already been mentioned: some of the additives being tested by researchers are known as acute poisons or carcinogens for humans and will, one hopes, not be promoted as food additives; other promising materials may, after due testing, exhibit chronic toxicity to humans or have anti-nutritional effects; yet others may, like the synthetic chemicals before them, be promoted and widely used before more subtle deleterious effects on consumers or the environment are discovered A second matter for caution is that there are no firm grounds for believing that many of these alternative additives will not ultimately give rise to resistance in the target pests. Most importantly, since it appears that consumer's concern about specific pesticides has broadened to encompass all pesticide residues, it is pertinent to ask whether any additives, synthetic or natural, will be acceptable to consumers in the future.

By contrast, research on biological control methods has seen much less growth. A search of literature databases has yielded 873 publications (862 in the last thirty years) concerning all arthropod natural enemies of storage pests or in storage habitats: this compares poorly with the figure of 202 for publications on just one botanical, neem, since 1971 It is also clear, as shown in Figure 2, that there has been no major expansion of research on these natural enemies over the past three decades Instead, the literature shows only a modest increase from about 15 publications per year in the early 1970s to between 25 and 60 per year in the mid-to late 1980s, and has since levelled off at an average of 37 per year through the 1990s. Furthermore, as discussed below, many of the references relate not to storage pest management but to the use of storage pests as convenient artificial hosts for mass-rearing of natural enemies of other pests, so the real increase in relevant research is even more modest, as indicated by the shaded sections of the histogram bars in Figure 2.

## Three decades of research on natural enemies in food storage

An analysis of this literature search has been undertaken to reveal characteristics and trends in research on, and use of, natural enemies in food storage, especially over the past thirty years. The analysis was primarily based on abstracts of the publications from secondary sources, especially CABI, CABPEST, AGRIS and AGRICOLA databases, plus NRI's own library database. The search was, in general, inclusive. Thus, references were included: (i) if the host or prey was a known post-harvest pest, whether of stored durable foodstuffs, or of roots and tubers, or of animal products (including honeycombs); (ii) if the natural enemy was well known as a parasite or predator in food storage, unless (as with some hymenopterans with a wide host range) the study was clearly focused on its role as a natural enemy of pre-harvest pests and included no reference to post-harvest pests; or (iii) if the study or survey concerned food storage habitats. The search deliberately excluded references to natural enemies in domestic habitats (especially in house dust) or in poultry houses, even where the host or prey species were also known as pests in food storage. All references were categorized in relation to: (i) whether they included field records of natural enemies, or reported laboratory or field trial results, or were reviews of previous records; (ii) the natural enemy (and host or prey) taxa involved; (iii) the status of the trophic relationship (known natural host or prey, possible natural host or prey, unnamed host or prey, or artificial host or prey); (iv) the type of study (population dynamics, taxonomy, field survey, etc); (v) the status of the host or prey (storage pest of durable food, other post-harvest pest, etc); and (vi) the country or region, especially for field studies.

The first notable feature to emerge from the analysis was the remarkable diversity of the arthropod natural enemy fauna, as illustrated by the taxonomic summary of the literature survey in Table 1. Even after discounting the 43 taxa (in the Phytoseiidae, Dermanyssidae, Chrysopidae, Ichneumonidae, Braconidae, Trichogrammatidae and Bethylidae) that appeared to be only artificial enemies of storage pests in laboratory studies, the search revealed 237 taxa of probable natural enemies of storage pests, possibly including over 250 arthropod species when allowance is made for records not identified to species level. It could of course be argued that this high level of biodiversity is merely a consequence of the geographical diversity of the literature search, which encompassed records from at least 90 countries. However, out of the total of 237 taxa of natural enemies listed in Table 1, at least 51 taxa (estimated to include over 60 species) were found in a survey of Indonesian food stores between 1978 and 1984 (Haines 1997), suggesting that these levels of diversity are indeed real, but are commonly overlooked or ignored.

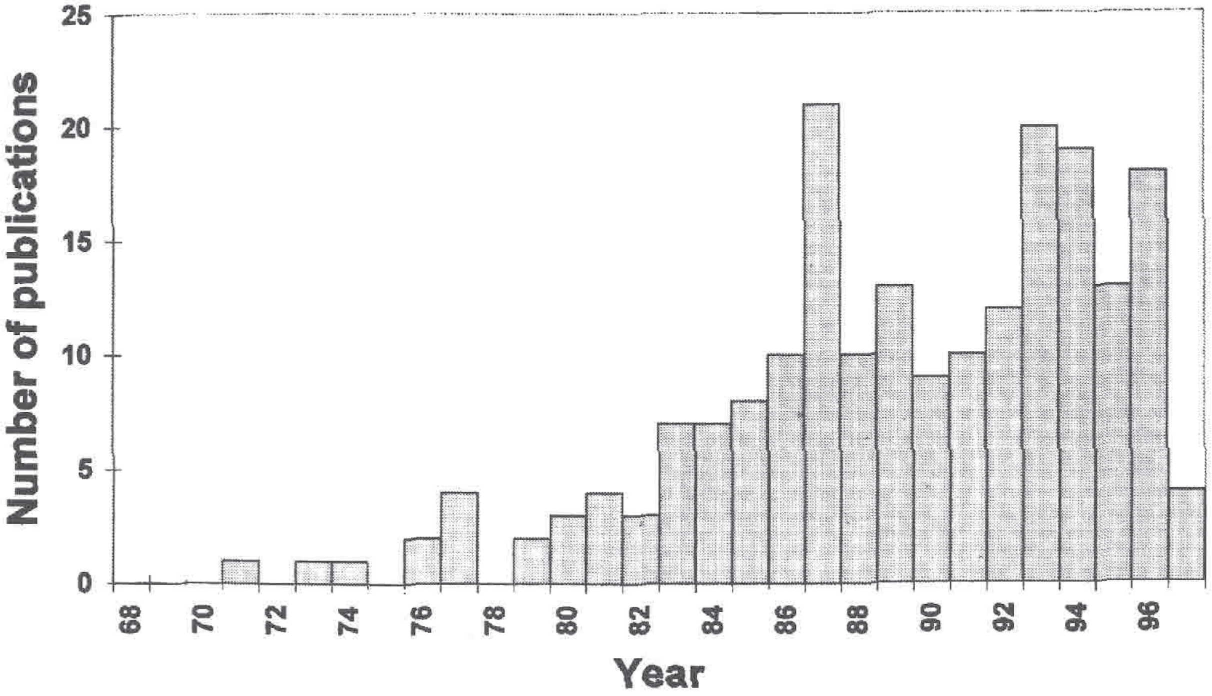

**Fig. 1.** Numbers of publications per year on the use of neem against storage pests, during the past three decades (data incomplete for 1997, and high in 1987 due to a neem conference).

Two-thirds of all the publications refer to laboratory or field trials, whereas only three-tenths refer to field observations (Table 2), though there is some overlap, with several papers including both. Table 2 also shows a 9:1 split between publications on pests of durable products (grain, pulses, dried roots, etc) and those on other post-harvest pests. A key factor in this balance has been the high level of interest in biological control of the potato tuber moth, *Phthorimaea operculella* (Zeller), which has been the target for most of the studies on biological control of pests of perishable products.

Table 2 also shows that 10% of all the references refer to the artificial mass-rearing of non-storage parasites and predators on storage pests. Such publications reached a peak in the late 1980s (see Figure 2), and have since decreased substantially. Excluding these, it is clear from Figure 2 that studies on natural enemies of storage pests have stagnated since the mid-1980s, in spite of the demand for ecologically-based alternatives to conventional synthetic insecticides. In addition, not all this research is directly relevant to storage ecosystems since it includes studies that use storage pests and their natural enemies as convenient laboratory organisms for fundamental academic research on models of parasitism or predation. In most cases, these studies are in the minority, but one species, the ichneumonid wasp *Venturia canescens* (Gravenhorst), has become a common laboratory model for host-parasite studies. As shown in Table 1, six publications refer to previous records of *V. canescens* as a parasite of storage pests, but only four references include field records of this wasp (LePelley 1959 in Kenya, Gloria 1972 in Peru, Waller 1982 in New Zealand, Awadallah et al. 1985a in Egypt): by contrast, 75 references describe laboratory studies on this species, accounting for over 15% of all laboratory or field trials on natural enemies of storage pests (excluding artificial mass-rearing studies).

An analysis of the geographic distribution of records of natural enemies of storage pests from the literature search (see Table 3) shows high levels of interest in the occurrence of these parasites and predators in Africa, Europe and North America, and strong interest in South Asia and the Middle East, but rather low interest elsewhere. It is not possible to do a similar geographic analysis of the laboratory-based research, either because the location of the research is not stated in the secondary sources used for the literature survey or because research relevant to one region is often performed in a different region. However, it is clear from an informal examination of the data that the regions with a higher than average proportion of laboratory research to field records are North America, the Middle East, and South and East Asia, though much research undertaken in Europe relates to natural enemies of storage pests in Africa.

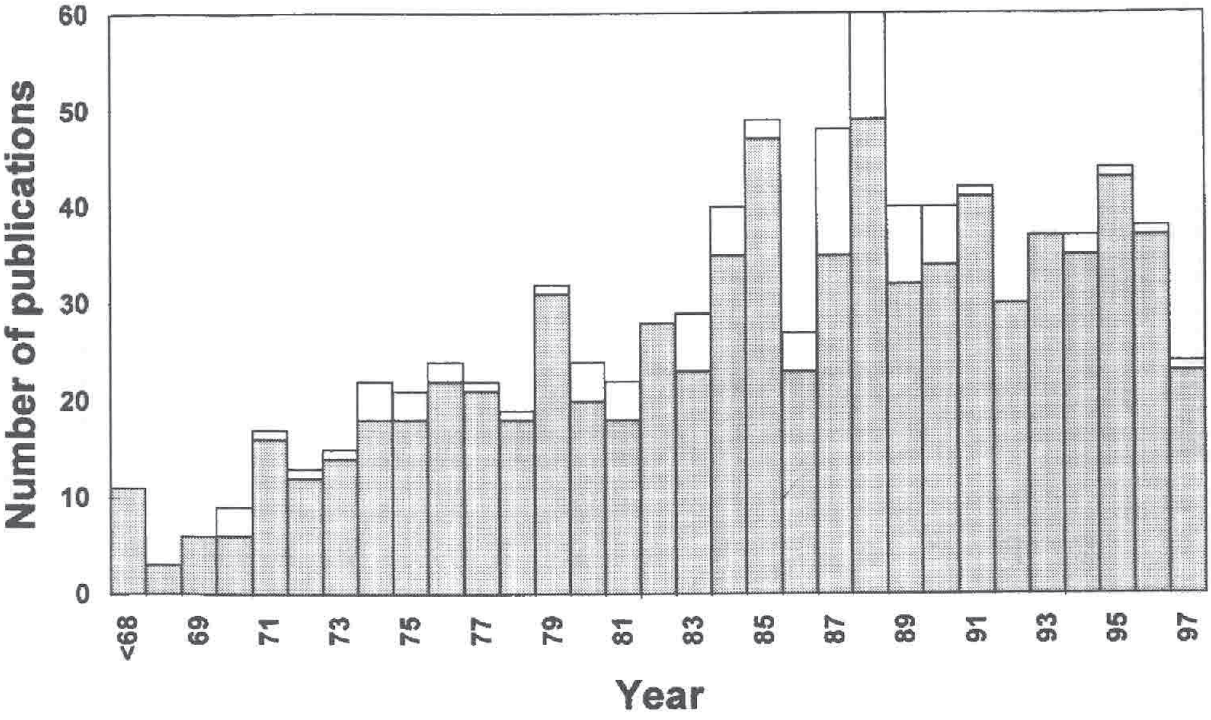

**Fig.2.** Numbers of publications per year on arthropod parasites and predators associated with post-harvest pests of stored food, or found in food storage. The unshaded sections of the histogram bars relate to publications describing artificial mass-rearing of parasites and predators on storage pests in the laboratory.

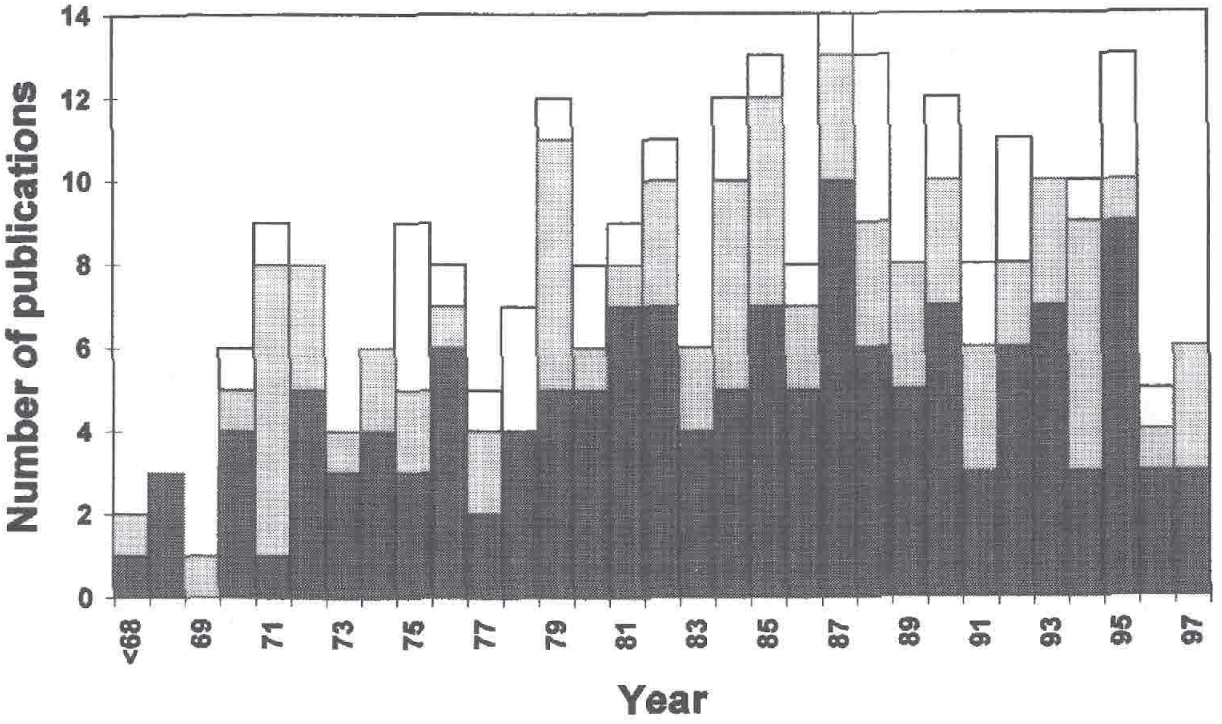

**Fig. 3.** Numbers of publications per year reporting field records of arthropod parasites and predators associated with post-harvest pests of stored food, or found in food storage. The dark-shaded sections of the histogram bars show records associated with a definite host or prey, the light-shaded sections show records with a possible host or prey, and the unshaded sections show records with no named host or prey.

A key feature of the literature on the potential use of natural enemies for storage pest management is the extent to which it is dominated by 'champions': i. e. individual author or team of authors who have studied and promoted the effect of particular natural enemies in relation to pest management. For example:. following early studies on *Cheyletus eruditus* (Schrank) in the United Kingdom by Solomon (1946), research in the Czech Republic by Zdarkova and his colleagues has contributed substantially to our knowledge of this cheyletid predator of acarid mites in temperate climate storage (Zdarkova 1979, 1986, 1994, 1997, Zdarkova & Horak 1990, Zdarkova & Pulpan 1973, Zdarkova et al. 1983); the predatory impact of the reduviid bug *Peregrinator biannulipes* (Montrouzier & Signoret) has been highlighted by a team in Egypt who have studied its biology in some detail (Awadallah et al. 1984a, 1985a, 1990, Tawfik et al. 1985a, 1985b, 1985c, 1987); our understanding of the biological control potential of the anthocorid bug *Xylocoris flavipes* (Reuter) is mainly due to the detailed studies of a team in the south-eastern USA over more than two decades, encompassing many aspects of development, behaviour, population dynamics, control efficacy, interactions with parasitoids, pesticide resistance and mass-rearing (Arbogast 1975, 1976, 1979a, 1979b, 1984, Arbogast and Throne 1997, Arbogast et al. 1977, Baker and Arbogast 1995, Baker and Throne 1995, Brower and Mullen 1990, Brower and Press 1988, 1992, Keever et al. 1986, Kraszpulski and Davis 1988, LeCato 1975, 1976, LeCato and Arbogast 1979, LeCato and Collins 1976, LeCato and Davis 1988, LeCato et al. 1977, Press 1989, Press and Flaherty 1978, 1985, Press et al. 1973, 1974a, 1974b, 1975, 1976, 1978, 1979, 1982); and a detailed understanding of the suppression of populations of the bruchids *Callosobruchus maculatus* (F.) and *Bruchidius atrolineatus* (Pic) by the trichogrammatid egg parasitoid *Uscana lariophaga* Steffan has emerged from work by an international team in the field in Niger and in their laboratories (Alebeek 1994, 1996a, 1996b, Alebeek and Groot 1997, Alebeek and Huis 1997, Alebeek et al. 1996a, 1996b, Alzouma 1995, Huignard et al. 1985, Huis and Appiah 1995, Huis et al. 1990, 1991, 1994, Lammers and Huis 1990, Ormel et al. 1995, Sagnia 1994).

**Table** 1. Arthropod predators and parasites of storage pests, or found in food storage habitats, reported in the literature of the latter half of the twentieth century, and the numbers of references (F – field records of natural enemies, L – laboratory experiments or field trials with natural enemies, R – reviews of natural enemies, X – laboratory studies of artificial mass-rearing on stored-product hosts or prey).

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| ARACHNIDA | | | | | |
| PSEUDOSCORPIONES | | | | | |
| Unidentified | *6 | 0 | 1 | 0 | 7 |
| Cheiridiidae | | | | | |
| *Cheiridium museorum* | 1 | 0 | 0 | 0 | 1 |
| Cheliferidae | | | | | |
| Unidentified | *2 | 0 | 0 | 0 | 2 |
| *Allowithius congicus* Beier | 1 | 0 | 0 | 0 | 1 |
| *Allowithius kaestneri* Vachon | 1 | 0 | 0 | 0 | 1 |
| *Chelifer* sp. | 0 | 1 | 0 | 0 | 1 |
| *Stenowithius ugandanus* Beier | 1 | 0 | 0 | 0 | 1 |
| *Withius niger* | 1 | 0 | 0 | 0 | 1 |
| *Withius piger* (Simon) | *1 | 0 | 0 | 0 | 1 |
| *Withius subruber* (Simon) | 1 | 0 | 0 | 0 | 1 |
| ARANEA | | | | | |
| Unidentified | *2 | 0 | 1 | 0 | 3 |
| ACARINA | | | | | |
| *PROSTIGMATA* | | | | | |
| Pyemotidae | | | | | |
| Unidentified | 2 | 0 | 1 | 0 | 3 |
| *Acarophenax* sp. | 2 | 0 | 0 | 0 | 2 |
| *Acarophenax assanovi* Livshits & Mitrofanov | 2 | 0 | 0 | 0 | 2 |
| *Acarophenax mahunkai* Steinkraus & Cross | 2 | 0 | 0 | 0 | 2 |
| *Acarophenax tribolii* Newstead & Duvall | *4 | 3 | 2 | 0 | 9 |
| *Pyemotes* sp. | *4 | 0 | 2 | 0 | 6 |
| *Pyemotes boylei* Krczal | 1 | 0 | 0 | 0 | 1 |
| *Pyemotes herfsi* Oudemans | 4 | 1 | 1 | 0 | 6 |
| *Pyemotes tritici* (Lagreze-Fossat & Montagne) | 4 | 13 | 3 | 0 | 20 |
| *Pyemotes ventricosus* (Newport) | 9 | 3 | 4 | 0 | 16 |
| *Pyemotes zwoelferi* Krczal | 0 | 2 | 0 | 0 | 2 |
| Cheyletidae | | | | | |
| Unidentified | 4 | 0 | 2 | 0 | 6 |
| *Acaropsella filipina* Corpuz-Raros | 1 | 0 | 0 | 0 | 1 |
| *Acaropsella volgini* (Gerson) | 1 | 0 | 0 | 0 | 1 |
| *Acaropsellina docta* (Berlese) | 6 | 5 | 2 | 0 | 13 |
| *Acaropsellina sollers* Rohdendorf | 6 | 2 | 2 | 0 | 10 |
| *Bak* sp. | *1 | 0 | 0 | 0 | 1 |
| *Caudacheles* sp. | *1 | 0 | 0 | 0 | 1 |
| *Chelacaropsis moorei* Baker | 1 | 0 | 0 | 0 | 1 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Chelachecaropsis bakeri* Attiah | 1 | 0 | 0 | 0 | 1 |
| *Chelacheles* sp. | *1 | 0 | 0 | 0 | 1 |
| *Chelacheles strabismus* Baker | 1 | 0 | 0 | 0 | 1 |
| *Cheletomimus cambio* Aheer, Akbar & Chaudhri | 1 | 0 | 0 | 0 | 1 |
| *Cheletomorpha* sp. | 1 | 0 | 0 | 0 | 1 |
| *Cheletomorpha hendersoni* Baker | 1 | 0 | 0 | 0 | 1 |
| *Cheletomorpha lepidopterorum* (Shaw) | 9 | 3 | 2 | 0 | 14 |
| *Cheletonata* sp | *1 | 0 | 0 | 0 | 1 |
| *Cheyletia papillifer* Volgin | 1 | 0 | 0 | 0 | 1 |
| *Cheyletus* sp. | 6 | 0 | 2 | 0 | 8 |
| *Cheyletus aversor* Rohdendorf | 6 | 0 | 1 | 0 | 7 |
| *Cheyletus eruditus* (Schrank) | 40 | 14 | 3 | 0 | 57 |
| *Cheyletus fortis* Oudemans | *1 | 0 | 0 | 0 | 1 |
| *Cheyletus malaccensis* Oudemans | *18 | 13 | 3 | 0 | 34 |
| *Cheyletus malayensis* Cunliffe | 0 | 1 | 0 | 0 | 1 |
| *Cheyletus trouessarti* Oudemans | 7 | 0 | 2 | 0 | 9 |
| *Eucheyletia flabellifera* (Michael) | 1 | 0 | 0 | 0 | 1 |
| *Eucheyletia harpyia* (Rohdendorf) | 1 | 0 | 0 | 0 | 1 |
| *Eucheyletia reticulata* Cunliffe | 1 | 0 | 0 | 0 | 1 |
| *Eucheyletia taurica* Volgin | 1 | 1 | 1 | 0 | 3 |
| *Grallacheles bakeri* De Leon | 2 | 0 | 0 | 0 | 2 |
| *Hemicheyletia tumidus* Qayyum & Chaudhri | 1 | 0 | 0 | 0 | 1 |
| *Hemicheyletia vescus* Qayyum & Chaudhri | 1 | 0 | 0 | 0 | 1 |
| *Ker* sp | *1 | 0 | 0 | 0 | 1 |
| *Ker bakeri* Zaher & Soliman | 2 | 0 | 0 | 0 | 2 |
| *Neoeucheyla* sp | 1 | 0 | 0 | 0 | 1 |
| *Nodele mu* Haines | 0 | 1 | 0 | 0 | 1 |
| *Nodele simplex* Wafa & Soliman | 0 | 1 | 0 | 0 | 1 |
| *Samsinakia gonocephalum* Fain | 1 | 0 | 0 | 0 | 1 |
| Bdellidae | | | | | |
| Unidentified | 1 | 0 | 0 | 0 | 1 |
| *Spinibdella* sp. | 1 | 0 | 0 | 0 | 1 |
| Cunaxidae | | | | | |
| Unidentified | 2 | 0 | 1 | 0 | 3 |
| *Cunaxa capreolus* | 1 | 0 | 0 | 0 | 1 |
| *Cunaxa setirostris* (Hermann) | *2 | 0 | 0 | 0 | 2 |
| *Neocunaxoides andrei* Baker & Hoffmann | 0 | 1 | 0 | 0 | 1 |
| Tydeidae | | | | | |
| Unidentified | 2 | 0 | 2 | 0 | 4 |
| *Oakvillea elalea* Momen & Sinha | 1 | 0 | 0 | 0 | 1 |
| *Paratydaeolus canadensis* Momen & Sinha | 1 | 0 | 0 | 0 | 1 |
| *Proctotydeus sinhai* Momen | 1 | 0 | 0 | 0 | 1 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Pronematus bachewingi* Baker | *1 | 0 | 0 | 0 | 1 |
| *Pronematus davisi* Baker | *1 | 0 | 0 | 0 | 1 |
| *Tydeus* sp. | *7 | 0 | 1 | 0 | 8 |
| *Tydeus australensis* Baker | *1 | 0 | 0 | 0 | 1 |
| *Tydeus brusti* Momen & Sinha | 1 | 0 | 0 | 0 | 1 |
| *Tydeus hughesea* Momen & Sinha | 1 | 0 | 0 | 0 | 1 |
| *Tydeus interruptus* Thor | 3 | 0 | 0 | 0 | 3 |
| *Tydeus manitobensis* Momen & Sinha | 1 | 0 | 0 | 0 | 1 |
| *MESOSTIGMATA* | | | | | |
| Ascidae | | | | | |
| Unidentified | 0 | 0 | 1 | 0 | 1 |
| *Arctoseius butleri* (Hughes) | 2 | 0 | 0 | 0 | 2 |
| *Blattisocius* sp. | 2 | 0 | 0 | 0 | 2 |
| *Blattisocius dentriticus* (Berlese) | *4 | 2 | 2 | 0 | 8 |
| *Blattisocius keegani* Fox | *14 | 3 | 1 | 0 | 18 |
| *Blattisocius mali* (Oudemans) | 3 | 0 | 2 | 0 | 5 |
| *Blattisocius quadridentatus* Haines | 1 | 0 | 0 | 0 | 1 |
| *Blattisocius tarsalis* (Berlese) | *15 | 10 | 4 | 0 | 29 |
| *Lasioseius africanus* | 0 | 0 | 0 | 1 | 1 |
| *Lasioseius berlesi* | 1 | 0 | 0 | 0 | 1 |
| *Lasioseius martini* Tjying | 1 | 0 | 0 | 0 | 1 |
| *Melichares agilis* Hering | 1 | 0 | 1 | 0 | 2 |
| *Proctolaelaps pygmaeus* (Mueller) | 1 | 0 | 0 | 0 | 1 |
| *Protogamasellus minutus* Hafez | 0 | 0 | 0 | 1 | 1 |
| Phytoseiidae | | | | | |
| Unidentified | 0 | 0 | 1 | 0 | 1 |
| *Amblyseius* sp. | *2 | 0 | 0 | 0 | 2 |
| *Amblyseius agrestis* | 0 | 0 | 0 | 1 | 1 |
| *Amblyseius arutanjani* | 0 | 0 | 0 | 1 | 1 |
| *Amblyseius herbarius* | 0 | 0 | 0 | 1 | 1 |
| *Amblyseius mckenzei* | 0 | 0 | 0 | 1 | 1 |
| *Neoseiulus barkeri* Hughes | 2 | 0 | 0 | 0 | 2 |
| Dermanyssidae | | | | | |
| Unidentified | 0 | 0 | 1 | 0 | 1 |
| *Androlaelaps casalis* (Berlese) | *9 | 2 | 2 | 0 | 13 |
| *Androlaelaps glasgowi* | 1 | 0 | 0 | 0 | 1 |
| *Haemogamasus pontiger* Berlese | 1 | 1 | 2 | 0 | 4 |
| *Hypoaspis* sp. | 0 | 0 | 1 | 0 | 1 |
| *Hypoaspis aculeifer* (Canestrini) | 2 | 9 | 0 | 0 | 11 |
| *Hypoaspis lubrica* Voigts & Oudemans | 0 | 0 | 1 | 0 | 1 |
| *Hypoaspis miles* (Berlese) | 0 | 3 | 1 | 1 | 5 |
| *Hypoaspis sardoa* (Berlese) | 0 | 0 | 1 | 0 | 1 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Hypoaspis vacuus* | 0 | 0 | 0 | 1 | 1 |
| *Laelaspis astronomicus* | 0 | 0 | 0 | 1 | 1 |
| Macrochelidae | | | | | |
| *Macrocheles* sp | *1 | 0 | 0 | 0 | 1 |
| *Macrocheles glaber* (Mueller) | 1 | 0 | 0 | 0 | 1 |
| INSECTA | | | | | |
| HEMIPTERA | | | | | |
| Reduviidae | | | | | |
| *Amphibolus venator* (Klug) | 1 | 1 | 2 | 0 | 4 |
| *Peregrinator biannulipes* (Montrouzier & Signoret) | *7 | 5 | 3 | 0 | 15 |
| *Reduvius* sp. | 0 | 0 | 1 | 0 | 1 |
| *Reduvius personatus* (Linnaeus) | 1 | 0 | 0 | 0 | 1 |
| *Vesbius* sp. | *1 | 0 | 0 | 0 | 1 |
| Anthocoridae | | | | | |
| Unidentified | 1 | 0 | 1 | 0 | 2 |
| *Calliodis* sp | 0 | 0 | 2 | 0 | 2 |
| *Cardiastethus nazarenus* Reuter | 1 | 0 | 0 | 0 | 1 |
| *Lyctocoris* sp. | 0 | 0 | 1 | 0 | 1 |
| *Lyctocoris campestris* Fabricius | 5 | 5 | 1 | 0 | 11 |
| *Lyctocoris cochici* | 1 | 0 | 1 | 0 | 2 |
| *Orius* sp. | 2 | 0 | 0 | 0 | 2 |
| *Scolpoides divareti* | 1 | 0 | 1 | 0 | 2 |
| *Xylocoris* sp. | *3 | 2 | 2 | 0 | 7 |
| *Xylocoris afer* (Reuter) | 2 | 0 | 1 | 0 | 3 |
| *Xylocoris flavipes* (Reuter) | *19 | 35 | 5 | 0 | 59 |
| *Xylocoris galactinus* (Fieber) | 2 | 2 | 1 | 0 | 5 |
| *Xylocoris sordidus* | 0 | 5 | 0 | 0 | 5 |
| Miridae | | | | | |
| *Termatophyllum insigne* (Reuter) | 1 | 2 | 0 | 0 | 3 |
| NEUROPTERA | | | | | |
| Chrysopidae | | | | | |
| *Chrysopa septempunctata* Wesmael | 0 | 0 | 0 | 1 | 1 |
| *Chrysoperla carnea* (Stephens) | 0 | 0 | 0 | 1 | 1 |
| DIPTERA | | | | | |
| Scenopinidae | | | | | |
| Unidentified | *2 | 0 | 0 | 0 | 2 |
| *Scenopinus* sp. | 2 | 0 | 0 | 0 | 2 |
| *Scenopinus fenestralis* (Linnaeus) | 4 | 0 | 2 | 0 | 6 |
| HYMENOPTERA | | | | | |
| Ichneumonidae | | | | | |
| *Campoplex haywardi* Blanchard | 3 | 0 | 0 | 0 | 3 |
| *Chrysoperla* sp. | 0 | 0 | 0 | 1 | 1 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Diadegma* sp. | 3 | 0 | 0 | 0 | 3 |
| *Diadegma chrysostictos* (Gmelin) | 0 | 0 | 1 | 0 | 1 |
| *Diadegma mollipla* (Holmgren) | 0 | 0 | 1 | 0 | 1 |
| *Diadegma stellenboschensis* (Cameron) | 2 | 1 | 0 | 0 | 3 |
| *Pristomerus* sp | 1 | 0 | 0 | 0 | 1 |
| *Temelucha* sp. | 4 | 1 | 0 | 0 | 5 |
| *Temelucha picta* (Holmgren) | 1 | 0 | 0 | 0 | 1 |
| *Venturia canescens* (Gravenhorst) | 4 | 75 | 6 | 0 | 85 |
| *Xenolytus bitinctus* (Gmelin) | 1 | 0 | 0 | 0 | 1 |
| Braconidae | | | | | |
| Unidentified | 1 | 0 | 0 | 0 | 1 |
| *Agathis unicolor* (Schrottky) | 1 | 0 | 0 | 0 | 1 |
| *Agathis unicolorata* Shenefelt | 1 | 0 | 0 | 0 | 1 |
| *Apanteles* sp. | 1 | 0 | 0 | 0 | 1 |
| *Apanteles appellator* | 2 | 0 | 0 | 0 | 2 |
| *Apanteles carpatus* Say | 0 | 1 | 2 | 0 | 3 |
| *Apanteles dignus* Muesebeck | 0 | 1 | 0 | 0 | 1 |
| *Apanteles galleriae* (Wilkinson) | 2 | 4 | 0 | 0 | 6 |
| *Apanteles scutellaris* Muesebeck | 0 | 1 | 0 | 0 | 1 |
| *Apanteles subandinus* Blanchard | 13 | 2 | 2 | 0 | 17 |
| *Apanteles trachalus* Nixon | 1 | 0 | 0 | 0 | 1 |
| *Bracon* sp. | 1 | 0 | 1 | 0 | 2 |
| *Bracon brevicornis* Wesmael | 2 | 15 | 0 | 1 | 18 |
| *Bracon hebetor* Say | *21 | 62 | 9 | 0 | 92 |
| *Chelonus* sp. | 0 | 0 | 0 | 1 | 1 |
| *Chelonus blackburni* Cameron | 1 | 2 | 0 | 10 | 13 |
| *Chelonus caucasicus* | 1 | 0 | 0 | 0 | 1 |
| *Chelonus curvimaculatus* Cameron | 2 | 0 | 0 | 0 | 2 |
| *Chelonus subcontractus* | 1 | 0 | 0 | 0 | 1 |
| *Cotesia ruficrus* | 1 | 0 | 0 | 0 | 1 |
| *Heterospilus prosopidis* Viereck | 0 | 3 | 0 | 7 | 10 |
| *Orgilus lepidus* Muesebeck | 5 | 1 | 0 | 0 | 6 |
| *Orgilus parcus* Turner | 1 | 0 | 0 | 0 | 1 |
| *Orgilus pimpinellae* | 2 | 0 | 0 | 0 | 2 |
| *Phanerotoma* sp. | 2 | 0 | 1 | 0 | 3 |
| *Phanerotoma flavitestacea* Fischer | 0 | 2 | 0 | 1 | 3 |
| *Phanerotoma ocularis* Kohl | 0 | 6 | 1 | 0 | 7 |
| *Platyspathius dinoderi* | 1 | 0 | 0 | 0 | 1 |
| *Prolatus aciculata* Sharma | 1 | 0 | 0 | 0 | 1 |
| *Spathius* sp. | 1 | 0 | 0 | 0 | 1 |
| *Stenobracon deesae* (Cameron) | 0 | 0 | 0 | 1 | 1 |
| *Stenocorse bruchivora* (Crawford) | 2 | 1 | 0 | 0 | 3 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Triaspis thoracicus* (Curtis) | 3 | 1 | 1 | 0 | 5 |
| Torymidae | | | | | |
| *Torymus atheatus* | 1 | 0 | 0 | 0 | 1 |
| Mymaridae | | | | | |
| *Alaptus globosicornis* Girault | 1 | 0 | 0 | 0 | 1 |
| Chalcididae | | | | | |
| *Antrocephalus* sp. | 0 | 0 | 1 | 0 | 1 |
| *Antrocephalus galleriae* | 0 | 1 | 0 | 0 | 1 |
| *Antrocephalus mitys* (Walker) | 2 | 2 | 0 | 0 | 4 |
| *Euchalcidia* sp. | *1 | 0 | 1 | 0 | 2 |
| *Euchalcidia caryobori* Hanna | *1 | 0 | 1 | 0 | 2 |
| Eurytomidae | | | | | |
| *Chryseida bennetti* Burks | 2 | 2 | 0 | 0 | 4 |
| Pteromalidae | | | | | |
| *Anisopteromalus apiovorus* | 1 | 0 | 0 | 0 | 1 |
| *Anisopteromalus calandrae* (Howard) | *35 | 55 | 6 | 0 | 96 |
| *Anisopteromalus caryedophagus* | 2 | 0 | 0 | 0 | 2 |
| *Cerocephala* sp. | *3 | 0 | 1 | 0 | 4 |
| *Cerocephala aquila* (Girault) | 0 | 0 | 1 | 0 | 1 |
| *Cerocephala dinoderi* Gahan | 2 | 0 | 3 | 0 | 5 |
| *Dibrachys boarmiae* (Walker) | 0 | 3 | 1 | 0 | 4 |
| *Dibrachys cavus* | 1 | 0 | 0 | 0 | 1 |
| *Dinarmus* sp | 4 | 0 | 0 | 0 | 4 |
| *Dinarmus acutus* | 2 | 0 | 0 | 0 | 2 |
| *Dinarmus basalis* (Rondani) | *9 | 24 | 2 | 0 | 35 |
| *Dinarmus colemani* (Crawford) | 2 | 0 | 2 | 0 | 4 |
| *Dinarmus vagabundus* (Timberlake) | 2 | 5 | 0 | 0 | 7 |
| *Lariophagus distinguendus* (Foerster) | *11 | 19 | 3 | 0 | 33 |
| *Mesopolobus* sp. | 1 | 0 | 0 | 0 | 1 |
| *Pteromalus cerealellae* (Ashmead) | 4 | 5 | 2 | 0 | 11 |
| *Theocolax* sp. | 0 | 1 | 0 | 1 | |
| *Theocolax elegans* (Westwood) | *15 | 12 | 8 | 0 | 35 |
| *Theocolax formiciformis* | 1 | 0 | 1 | 0 | 2 |
| Encyrtidae | | | | | |
| *Copidosoma desantisi* Annecke & Mynhardt | 3 | 0 | 0 | 0 | 3 |
| *Copidosoma koehleri* Blanchard | 12 | 12 | 2 | 0 | 26 |
| *Copidosoma oeceticola* De Santis | 1 | 0 | 0 | 0 | 1 |
| *Copidosoma phthorimaeae* Logvinovskaya | 1 | 0 | 0 | 0 | 1 |
| *Copidosoma uruguayensis* Tachikawa | 1 | 0 | 0 | 0 | 1 |
| *Zeteticontus* sp. | 1 | 1 | 1 | 0 | 3 |
| *Zeteticontus brasiliensis* Rao | 1 | 0 | 0 | 0 | 1 |
| *Zeteticontus ceylonicus* Rao | 1 | 0 | 0 | 0 | 1 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Zeteticontus punctiscutellum* Rao | 1 | 0 | 0 | 0 | 1 |
| *Zeteticontus utilis* Noyes | 1 | 2 | 0 | 0 | 3 |
| Eupelmidae | | | | | |
| *Eupelmus* sp. | 3 | 0 | 0 | 0 | 3 |
| *Eupelmus cushmani* | 1 | 0 | 0 | 0 | 1 |
| *Eupelmus orientalis* (Crawford) | 1 | 3 | 1 | 0 | 5 |
| *Eupelmus vuilleti* (Crawford) | 7 | 13 | 0 | 0 | 20 |
| Eulophidae | | | | | |
| *Horismenus* near *depressus* | 1 | 0 | 0 | 0 | 1 |
| Platygasteridae | | | | | |
| *Synopeas* sp. | 0 | 1 | 0 | 0 | 1 |
| Trichogrammatidae | | | | | |
| *Trichogramma* sp. | 0 | 3 | 1 | 29 | 33 |
| *Trichogramma achaeae* Nagaraja & Nagarkatti | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma aurosa* | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma australicum* Girault | 0 | 1 | 0 | 1 | 2 |
| *Trichogramma brasiliensis* (Ashmead) | 0 | 0 | 0 | 3 | 3 |
| *Trichogramma brassicae* | 0 | 1 | 0 | 0 | 1 |
| *Trichogramma buesi* | 0 | 1 | 0 | 0 | 1 |
| *Trichogramma cacoeciae* Marchal | 0 | 0 | 0 | 3 | 3 |
| *Trichogramma chilonis* (Ishii) | 0 | 1 | 0 | 2 | 3 |
| *Trichogramma chilotraeae* Nagaraja & Nagarkatti | 0 | 1 | 0 | 1 | 2 |
| *Trichogramma dendrolimi* | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma embryophagum* | 0 | 1 | 0 | 7 | 8 |
| *Trichogramma euproctidis* | 0 | 1 | 0 | 0 | 1 |
| *Trichogramma evanescens* Westwood | 2 | 8 | 1 | 6 | 17 |
| *Trichogramma exiguum* | 0 | 0 | 0 | 2 | 2 |
| *Trichogramma ingricum* | 0 | 0 | 0 | 3 | 3 |
| *Trichogramma ivelae* Pang & Chen | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma japonicum* Ashmead | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma maidis* Pintureau & Voegele | 0 | 0 | 0 | 9 | 9 |
| *Trichogramma minutum* Riley | 0 | 1 | 0 | 3 | 4 |
| *Trichogramma oatmani* de la Torre Callejas | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma ostriniae* | 0 | 0 | 0 | 3 | 3 |
| *Trichogramma parkeri* | 1 | 0 | 0 | 0 | 1 |
| *Trichogramma perkinsi* | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma pintoi* | 0 | 0 | 0 | 2 | 2 |
| *Trichogramma platneri* | 0 | 0 | 0 | 2 | 2 |
| *Trichogramma pretiosum* Riley | 3 | 14 | 0 | 2 | 19 |
| *Trichogramma rhenana* Voegele & Russo | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma semblidis* | 0 | 0 | 0 | 3 | 3 |
| *Trichogramma silvestre* | 0 | 0 | 0 | 3 | 3 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| *Trichogramma telengai* Sorokina | 0 | 0 | 0 | 1 | 1 |
| *Trichogramma turkeiensis* | 0 | 0 | 0 | 1 | 1 |
| *Trichogrammatoidea* sp. | 0 | 0 | 0 | 1 | 1 |
| *Trichogrammatoidea lutea* (Girault) | 0 | 0 | 0 | 1 | 1 |
| *Trichogrammatoidea nana* (Zehnt) | 0 | 0 | 0 | 1 | 1 |
| *Uscana* sp. | 4 | 0 | 0 | 0 | 4 |
| *Uscana caryedoni* Viggiani | 3 | 0 | 0 | 0 | 3 |
| *Uscana lariophaga* Steffan | 6 | 10 | 0 | 0 | 16 |
| *Uscana mukerjii* (Mani) | 2 | 2 | 1 | 0 | 5 |
| *Uscana senex* Fursov | 1 | 0 | 0 | 0 | 1 |
| Bethylidae | | | | | |
| *Cephalonomia* sp. | 2 | 0 | 0 | 0 | 2 |
| *Cephalonomia gallicola* (Ashmead) | 3 | 3 | 0 | 0 | 6 |
| *Cephalonomia tarsalis* (Ashmead) | *2 | 0 | 2 | 0 | 4 |
| *Cephalonomia waterstoni* Gahan | *5 | 5 | 2 | 0 | 12 |
| *Goniozus nephantidis* | 0 | 0 | 0 | 1 | 1 |
| *Holepyris* sp | 2 | 1 | 0 | 0 | 3 |
| *Holepyris hawaiiensis* (Ashmead) | *5 | 0 | 2 | 0 | 7 |
| *Holepyris sylvanidis* (Brhes) | *7 | 1 | 3 | 0 | 11 |
| *Laelius pedatus* (Say) | 0 | 9 | 0 | 0 | 9 |
| *Laelius utilis* | 1 | 2 | 0 | 0 | 3 |
| *Plastanoxus munroi* Richards | *1 | 0 | 2 | 0 | 3 |
| *Plastanoxus westwoodi* (Kieffer) | *1 | 1 | 1 | 0 | 3 |
| COLEOPTERA | | | | | |
| Carabidae | | | | | |
| Unidentified | *1 | 0 | 0 | 0 | 1 |
| *Bradycellus harpalinus* (Serville) | 1 | 0 | 0 | 0 | 1 |
| Staphylinidae | | | | | |
| Various | *1 | 0 | 1 | 0 | 2 |
| Histeridae | | | | | |
| Various | 0 | 0 | 1 | 0 | 1 |
| *Carcinops pumilio* (Erichson) | 1 | 0 | 1 | 0 | 2 |
| *Carcinops troglodytes* (Paykull) | *2 | 0 | 1 | 0 | 3 |
| *Hypocacculus metallescens* (Erichson) | *1 | 0 | 0 | 0 | 1 |
| *Saprinus* sp. | *1 | 0 | 0 | 0 | 1 |
| *Teretrius* sp. | 0 | 0 | 1 | 0 | 1 |
| *Teretrius nigrescens* (Lewis) | 10 | 7 | 6 | 0 | 23 |
| *Teretrius punctulatus* Fahraeus | 1 | 0 | 0 | 0 | 1 |
| Cleridae | | | | | |
| *Necrobia rufipes* (DeGeer) | 0 | 0 | 2 | 0 | 2 |
| *Thaneroclerus buqueti* (Lefre) | *4 | 0 | 4 | 0 | 8 |
| *Tillus notatus* Klug | 3 | 3 | 1 | 0 | 7 |

| Taxon | F | L | R | X | All |
|---|---|---|---|---|---|
| Rhizophagidae | | | | | |
| Unidentified | *1 | 0 | 1 | 0 | 2 |
| Passandridae | | | | | |
| *Laemotmetus rhizophagoides* (Walker) | *1 | 0 | 1 | 0 | 2 |
| Coccinellidae | | | | | |
| Various | *1 | 0 | 1 | 0 | 2 |
| Colydiidae | | | | | |
| Unidentified | 0 | 0 | 1 | 0 | 1 |
| Dermestidae | | | | | |
| *Anthrenus scrophulariae* | 1 | 0 | 0 | 0 | 1 |
| *Dermestes ater* DeGeer | 0 | 0 | 1 | 0 | 1 |
| Trogossitidae | | | | | |
| *Tenebroides mauritanicus* (Linnaeus) | *1 | 0 | 3 | 0 | 4 |
| Tenebrionidae | | | | | |
| *Alphitobius diaperinus* (Panzer) | 1 | 2 | 0 | 0 | 3 |
| *Lyphia* sp. | 0 | 0 | 1 | 0 | 1 |
| *Lyphia depressa* Hinton | 1 | 0 | 0 | 0 | 1 |
| *Lyphia orientalis* Blair | *2 | 0 | 1 | 0 | 3 |
| *Tribolium castaneum* (Herbst) | 1 | 0 | 0 | 0 | 1 |

* field records include natural enemies found in a survey in Indonesia, 1978 – 84 (Haines, 1997).

**Table 2.** Numbers of publications relating to field records, laboratory or field trials, and reviews of previous records, categorized by the status of the parasite or predator in relation to the host or prey, and by the habit of the host or prey (*S* – storage pest of durable food products, *P* – other post-harvest pest, *SP* – mixture of storage pest and other post-harvest pest, *N* – not a post-harvest pest, *U* – unnamed pest).

| Field records | *S* | *SP* | *P* | *N* | *U* | *All* |
|---|---|---|---|---|---|---|
| Definite natural host or prey | 116 | 0 | 27 | 3 | 0 | 146 |
| Possible natural host or prey | 72 | 0 | 5 | 0 | 0 | 77 |
| Unnamed host or prey | 36 | 0 | 1 | 1 | 3 | 41 |
| Artificial host or prey | 0 | 0 | 0 | 0 | 0 | 0 |
| All | 224 | 0 | 33 | 4 | 3 | 264 |

| Laboratory or field trials | *S* | *SP* | *P* | *N* | *U* | *All* |
|---|---|---|---|---|---|---|
| Definite natural host or prey | 340 | 4 | 32 | 1 | 1 | 378 |
| Possible natural host or prey | 70 | 5 | 15 | 0 | 0 | 90 |
| Unnamed host or prey | 10 | 0 | 0 | 0 | 16 | 26 |
| Artificial host or prey | 80 | 2 | 4 | 0 | 0 | 86 |
| All | 500 | 11 | 51 | 1 | 17 | 580 |

| Reviews of previous records | S | SP | P | N | U | All |
|---|---|---|---|---|---|---|
| Definite natural host or prey | 44 | 0 | 5 | 0 | 0 | 49 |
| Possible natural host or prey | 10 | 0 | 0 | 1 | 0 | 11 |
| Unnamed host or prey | 3 | 1 | 0 | 0 | 8 | 12 |
| Artificial host or prey | 1 | 0 | 0 | 0 | 0 | 1 |
| All | 58 | 1 | 5 | 1 | 8 | 73 |

**Table** 3. Numbers of publications on occurrence of natural enemies of storage pests by geographic region, categorized as original field records or reviews of previous records.

| Region | Field records | Reviews | All records |
|---|---|---|---|
| Global-several regions | 5 | 26 | 31 |
| North America | 39 | 9 | 48 |
| Meso-America & Caribbean | 7 | 4 | 11 |
| South America | 11 | 0 | 11 |
| Africa | 49 | 11 | 60 |
| Middle East | 28 | 1 | 29 |
| Europe | 48 | 8 | 56 |
| West & Central Asia | 8 | 1 | 9 |
| South Asia | 33 | 4 | 37 |
| East Asia | 17 | 4 | 21 |
| South-East Asia | 9 | 1 | 10 |
| Australia & Pacific | 10 | 2 | 12 |
| All | 264 | 71 | 335 |

However, in spite of these intensive studies-especially the last two examples-and the positive results they have produced, these proven examples have not been widely adopted as a biological control component in integrated pest management in food storage. As noted earlier, classical biological control techniques with various species of parasitoid wasps (ichneumonids, braconids and encyrtids) have been tested and used against the potato tuber moth, *P. operculella*, in several countries, but this is not generally true of other post-harvest pests. The one exception is the histerid, *Teretrius nigrescens* (Lewis): a predator of the larger grain borer, *Prostephanus truncatus* (Horn). The predation of this beetle on *P. truncatus* in Meso-America was first reported by Haines (1981) on the basis of evidence from maize samples collected in Mexico in the 1970s. This led Rees to undertake laboratory studies on the biology of the predator and to continue these into field trials (Rees 1985, 1987, 1989, 1990, 1991, 1992). Through the late 1980s, interest in this predator increased rapidly and it was introduced into West and East Africa from the early 1990s (Markham et al 1994). After initial doubts about its impact on *P truncatus* populations, it is now well-established in and beyond the release areas, and recent impact assessments suggest that the predator is having a positive effect (Hodges in press).

A feature of the above examples is that they have focused on specific natural enemies of target pest groups and have used a combination of field and laboratory studies to research the relationship and develop potential biological control systems. In practice, many other authors either focus on a laboratory investigation of a single natural enemy or attempt wide-ranging surveys to catalogue the natural enemies present in a post-harvest system. The first approach runs the risk of developing a detailed understanding about a predator-prey or parasite-host relationship that may not have any practical application in the field. The second approach can give a holistic view of the complexity of communities but often fails to identify the inter-relationships between natural enemies and pests. Ideally, field samples would be observed closely to record incidents of predation and pest species from the samples would be isolated and kept to breed out parasites; in practice, both techniques are extremely time-consuming and yield only infrequent results. The data in Figure 3 illustrate this problem with field observations: many of the records do not include information on definite hosts or prey of the natural enemies, and there is no indication that our understanding is improving significantly year on year.

The survey of arthropods in Indonesian food stores reported by Haines (1997) is an example of the second approach described above and yielded definite evidence of just one suspected, but previously unconfirmed, relationship: the predation of the cheyletid mite *Cheyletus malaccensis* Oudemans on the common and abundant psocopteran *Liposcelis entomophila* (Enderlein). It did, however, reveal a notable diversity of natural enemies, as shown in Table 4. Whilst many of these were found infrequently, it is remarkable how many occurred regularly, especially the pseudoscorpions, cheyletids, tydeids, ascids, anthocorids, braconids, pteromalids and bethylids. Another point to note is that several of those species which occurred moderately frequently, such as the tydeid *Tydeus australensis* Baker, have rarely been reported by others and have unknown habits. A final point, which emphasizes the paucity of our understanding of natural enemies in storage habitats, is that several of the taxa, especially in the Cheyletidae, could not be named because they were undescribed species.

**Table 4.** Arthropod predators and parasites found in food stores in Indonesia in a survey 1978 – 1984, showing the total number of records of each taxon, and the percentage they represented in the total number of samples (1235).

| Taxon | No. | % |
|---|---|---|
| ARACHNIDA | | |
| PSEUDOSCORPIONES | | |
| Unidentified | 17 | 1.38 |
| Cheliferidae | | |
| Unidentified | 32 | 2.59 |
| *Withius piger* (Simon) | 1 | 0.08 |
| ARANEA | | |
| Unidentified | 54 | 4.37 |
| ACARINA | | |
| *PROSTIGMATA* | | |
| Pyemotidae | | |
| *Acarophenax tribolii* Newstead & Duvall | 2 | 0.16 |
| *Pyemotes* sp. | 3 | 0.24 |
| Cheyletidae | | |
| *Bak* sp. | 1 | 0.08 |
| *Caudacheles* sp. | 1 | 0.08 |
| *Chelacheles* sp. | 18 | 1.46 |
| *Cheletonata* sp. | 1 | 0.08 |
| *Cheyletus* sp. | 30 | 2.43 |
| *Cheyletus fortis* Oudemans | 27 | 2.19 |
| *Cheyletus malaccensis* Oudemans | 299 | 24.21 |
| *Ker* sp. | 7 | 0.57 |
| Cunaxidae | | |
| *Cunaxa setirostris* (Hermann) | 1 | 0.08 |
| Tydeidae | | |
| *Pronematus* sp. | 5 | 0.40 |
| *Pronematus bachewingi* Baker | 20 | 1.62 |
| *Pronematus davisi* Baker | 3 | 0.24 |
| *Tydeus* sp. | 3 | 0.24 |
| *Tydeus australensis* Baker | 66 | 5.34 |
| *MESOSTIGMATA* | | |
| Ascidae | | |
| *Blattisocius* sp. | 2 | 0.16 |
| *Blattisocius dentriticus* (Berlese) | 5 | 0.40 |
| *Blattisocius keegani* Fox | 42 | 3.40 |
| *Blattisocius tarsalis* (Berlese) | 41 | 3.32 |
| Phytoseiidae | | |
| *Amblyseius* sp. | 3 | 0.24 |
| Dermanyssidae | | |
| *Androlaelaps casalis* (Berlese) | 3 | 0.24 |
| Macrochelidae | | |

| Taxon | No. | % |
|---|---|---|
| *Macrocheles* sp. indet | 1 | 0.08 |
| *Macrocheles* sp. A | 2 | 0.16 |
| *Macrocheles* sp. B | 1 | 0.08 |
| INSECTA | | |
| HEMIPTERA | | |
| Reduviidae | | |
| Unidentified | 3 | 0.24 |
| *Peregrinator biannulipes* (Montrouzier & Signoret) | 3 | 0.24 |
| *Vesbius* sp. | 1 | 0.08 |
| Anthocoridae | | |
| Unidentified | 18 | 1.46 |
| *Xylocoris* sp. indet. | 49 | 3.97 |
| *Xylocoris* sp. A | 5 | 0.40 |
| *Xylocoris flavipes* (Reuter) | 108 | 8.74 |
| DIPTERA | | |
| Scenopinidae | | |
| Unidentified | 2 | 0.16 |
| HYMENOPTERA | | |
| Braconidae | | |
| Unidentified | 9 | 0.73 |
| *Bracon* sp. | 7 | 0.57 |
| *Bracon hebetor* Say | 38 | 3.08 |
| Evaniidae | | |
| Unidentified | 1 | 0.08 |
| Chalcididae | | |
| Unidentified | 1 | 0.08 |
| *Euchalcidia* sp. | 6 | 0.49 |
| *Euchalcidia caryobori* Hanna | 1 | 0.08 |
| Pteromalidae | | |
| Unidentified | 4 | 0.32 |
| *Anisopteromalus calandrae* (Howard) | 43 | 3.48 |
| *Cerocephala* sp. | 2 | 0.16 |
| *Dinarmus basalis* (Rondani) | 6 | 0.49 |
| *Lariophagus distinguendus* (Foerster) | 3 | 0.24 |
| *Theocolax elegans* (Westwood) | 63 | 5.10 |
| Mymaridae | | |
| Unidentified | 3 | 0.24 |
| Bethylidae | | |
| Unidentified | 6 | 0.49 |
| *Cephalonomia tarsalis* (Ashmead) | 24 | 1.94 |
| *Cephalonomia waterstoni* Gahan | 39 | 3.16 |
| *Holepyris hawaiiensis* (Ashmead) | 4 | 0.32 |
| *Holepyris sylvanidis* (Brhes) | 17 | 1.38 |
| *Plastanoxus* sp. | 1 | 0.08 |
| *Plastanoxus munroi* Richards | 3 | 0.24 |
| *Plastanoxus westwoodi* (Kieffer) | 7 | 0.57 |
| COLEOPTERA | | |

| Taxon | No. | % |
|---|---|---|
| Carabidae | | |
| Unidentified | 6 | 0.49 |
| Harpalinae (17 spp.) | 19 | 1.54 |
| Scaritinae (3 spp.) | 4 | 0.32 |
| Staphylinidae | | |
| Unidentified (3 spp.) | 16 | 1.30 |
| Histeridae | | |
| *Carcinops* sp. | 1 | 0.08 |
| *Carcinops troglodytes* (Paykull) | 6 | 0.49 |
| *Hypocacculus metallescens* (Erichson) | 1 | 0.08 |
| *Saprinus* sp. | 1 | 0.08 |
| Cleridae | | |
| *Thaneroclerus buqueti* (Lefre) | 23 | 1.86 |
| Rhizophagidae | | |
| Unidentified | 2 | 0.16 |
| Passandridae | | |
| *Laemotmetus rhizophagoides* (Walker) | 1 | 0.08 |
| Coccinellidae | | |
| Unidentified | 9 | 0.73 |
| Tenebrionidae | | |
| *Lyphia orientalis* Blair | 2 | 0.16 |

## Future Perspectives

As noted previously (e. g. by Haines 1982, 1994), reliable and wide-ranging check-lists of arthropods in storage are uncommon, especially for mites, and detailed ecological studies of stored-product arthropod communities are rare: both are particularly rare for warmer climates, where the communities are more diverse and complex, and the rate of change of population dynamics is greater. Yet without the ' building blocks ' of such systematic and ecological information, it is difficult to see that there can be any significant leap forward in our understanding of the role of natural enemies in storage pest systems, and of the potential use of biological control in integrated pest management.

Fourteen years ago, Arbogast (1984) presented a paper to the Third IWCSPE in Kansas, which reviewed the opportunities for the use of natural enemies as control agents for stored-product insects. It is pertinent to consider how far we have progressed in those 14 years. Indubitably, there have been some successes and even significant advances: the release of *Teretrius nigrescens* against larger grain borer, and the ongoing studies of biological control of bruchids in West Africa, are illustrations of this. Nevertheless, in spite of the steadily increasing demand for alternatives to conventional synthetic pesticides over the past two decades, there has been no major increase in research on the ecology of stored-product communities, on the occurrence and diversity of natural enemies in storage, on the efficacy and economics of biological control agents, or on novel approaches to the possible use of natural enemies in integrated management of storage pests. Instead, most of the alternatives under investigation relate to additives of one form or another.

This failure to develop – or even to research – biological control alternatives, as demand increases, seems counter-intuitive. There is perhaps a parallel in the increasing demand of the international community for attention to issues of biodiversity, environment and conservation, whilst taxonomic and systematic expertise and services in many countries are withering due to lack of funding and education. In both cases, demand has increased due to public opinion, environmental lobbying and government support for change, whereas resources have been diverted from the essential long-term ' public-good ' research that needs to be undertaken to identify sustainable responses to the demand. This represents a conflict of policy in public research that needs to be addressed and debated if we wish to find truly sustainable and environmentally-acceptable alternatives to conventional pesticides.

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