Ecology and IPM of Insects at Grain Elevators and Flat Storages

D. W. HAGSTRUM¹, P. W. FLINN², C. R. REED³ AND T. W. PHILLIPS⁴

¹USDA-ARS (retired), 2328 Cheryl Terr., Manhattan, KS 66502
²USDA-ARS Center for Grain & Animal Health Research, Manhattan, Kansas, USA
³Department of Grain Science and Industry, Kansas State University, KS, USA
⁴Department of Entomology, Kansas State University, KS, USA

ABSTRACT Cost-effectiveness of insect pest management depends upon its integration with other elevator operations. Successful integration may require consideration of insect ecology. Field infestation has not been observed for grain received at elevators. Grain may be infested during harvest by residual insect infestations in the combines or may be infested soon after grain is loaded into bins by residual insect infestations at the elevator. A total of 61 species of insects in 26 families and 6 orders have been reported at elevators or in flat storages. At grain elevators, the species composition in grain residues differed from that in the wheat stored in bins. Insect populations in wheat increased from June to October, then leveled off and declined as fall and winter temperatures cooled the grain. Often less than 20% of the bins had economically important insect infestations and generally the bins with high insect densities were close to other highly infested bins. The numbers of insects at elevators decreased with the depth below the surface as they did on farm. Insects are moved through the marketing systems with grain, but low sampling rates result in few of the infestations being discovered. Wheat with high-test weight was less likely to be discounted for insects than wheat with a lower test weight. Pest management practices were very effective for 20 out of 25 flat storages and infestations in others were not allowed to reach densities which would result in an infested designation on the grade certificate. Insect ecology is relevant to pest management in many ways. Segregating grain by moisture content and drying are important because low moisture grain is less susceptible to insects. Insects are highly mobile and grain residues inside and outside bins at an elevator that are not removed are a common source of the insects that infest other stored grain. Blending grain during unloading can minimize the amount of grain infested. Early summer aeration during the coldest hours of the night can slow insect population growth. Insect densities are highest near the surface where retention of the fumigant is most difficult. Knowing insect infestation levels can be important for profitable grain marketing.

KEY WORDS: Distribution, seasonal trends, residual infestations, aeration, fumigation

INTRODUCTION

Cost-effectiveness of insect pest management depends upon its integration with other elevator operations and successful integration may require consideration of insect ecology. In the USA, commercial grain storage facilities are called elevators (Reed, 2006). Elevator operation practices have been discussed by Bailey (1992), Reed (2006) and Hagstrum et al. (2008). The ecology of grain infesting insects has been studied more extensively on farms than at...
grain elevators (Hagstrum et al., 1996; Hagstrum and Subramanyam, 2006). Various aspects of insect ecology that have been studied at elevators are reviewed in this paper and examples of the importance of insect ecology to pest management are discussed.

INITIAL INSECT INFESTATION

Field infestation has not been observed for wheat received at elevators. Chao et al. (1953) concluded that insects found at elevators were not infesting wheat in the field prior to harvest in the state of Washington, USA. Insects also have not been reported to infest wheat in the field in Kansas (Cotton and Winburn, 1941; Walkden, 1951) or Oklahoma (Cuperus unpublished data in Gates, 1995).

White (1985), by taking 55 kilogram grain samples from trucks delivering wheat to elevators directly from the field in Australia, found average estimated densities of only 3.6 insects per ton in 1977 and 0.6 insects per ton in 1978. These insects were probably from wheat residues in the combine. Similar samples from wheat held on farm for a short time prior to delivery in 1976, 1977 and 1978 had average estimated densities of 4.4 to 43.8 insects per ton. Wheat stored on farm for 2 months prior to delivery in 1978 had an average estimated density of 102.8 insects per ton.

Some infested wheat that has been stored on farms may be delivered to elevators along with newly-harvested wheat (Hagstrum et al., 2008). The average combined numbers of Rhyzopertha dominica (Fabricius) and Tribolium castaneum (Herbst) in wheat stored on farm for a period of time before being delivered to a country or a terminal elevator (4.18 insects/kg) was higher than those in wheat stored at country elevators for a period of time before being delivered to terminal elevators (0.50 insects/kg). Higher insect densities may be a result of the grain being stored in smaller bins on farms which make grain more accessible to insects although 80% of the wheat samples in both cases did not have live insects.

In Kansas, probe trap catches just below the grain surface indicated that insects present at elevators infest newly-harvested wheat soon after being loaded into bins (Reed et al., 2001). These probe trap catches did not predict well the likelihood of future insect problems. Toews et al. (2005) found that probe traps one meter below the surface provided a better estimate of absolute insect density than those near the surface.

INSECT POPULATION DURING STORAGE

A total of 61 species of insects in 26 families and 6 orders have been reported at elevators or in flat storages in 36 studies (Table 1). Some of these species have been found in grain received at elevators, grain stored in concrete or steel bins at elevators, or grain stored in flat storages, while others have been found in empty bins, outside bins or outside elevators. Many have been found at more than one of these locations. Twenty-two of these species have been reported only once. Hagstrum and Subramanyam (2006) reported another 43 species that have been found at elevators or in flat storages. With more than 500 insect species reported in their book to be associated with grain, more species are likely to be reported to be associated with grain elevators as the insect populations at elevators are studied more in the future.

The changes in density of R. dominica over the storage period in wheat moving through the marketing system to port elevators in the United States (Fig. 1) was plotted by Hagstrum and Heid (1988) based on data from Storey et al. (1982a). Similar information on insect infestation levels as grain moved through the marketing system in the United States has been provided by Harris et al. (1952) and Butler and Mickel (1955) for wheat, and Harris et al. (1953) for maize, but their results were reported as the total numbers of insects and generally the numbers of each species were not given. For the two studies on wheat, the total numbers of insects increased as wheat moved through the marketing system and insect populations had more time to grow. Swenson and Tunnock (1957) sampled grain stored on farms and grain stored at elevators in Oregon, but they unfortunately combined insect data for farms with that for elevators. Cole and Cox (1981) stud-
<table>
<thead>
<tr>
<th>Insect species</th>
<th>Order</th>
<th>Family</th>
<th>Reports by location studied</th>
<th>Empty Grain in bins</th>
<th>Flat storages</th>
<th>Grain in bins</th>
<th>Grain outside</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahasverus advena (Waltl)</td>
<td>Col.</td>
<td>Silvanidae</td>
<td></td>
<td>CS4 N04, A01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alphitobius diaperinus (Panzer)</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>A-M88, N04, A05, R03</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alphitobius bifasciatus (Say)</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>A01, A05, R03</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anisopteromalus calandrae (Howard)</td>
<td>Hym.</td>
<td>Pteromalidae</td>
<td>R03, A-M88, N04</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attagenus unicolor (Brahm)</td>
<td>Col.</td>
<td>Dermestidae</td>
<td>A05, A01</td>
<td>C54, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carcinops pumilio (Erichson)</td>
<td>Col.</td>
<td>Histeridae</td>
<td>A01</td>
<td>C54, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpophilus dimidiatus (Fabricius)</td>
<td>Col.</td>
<td>Nitidulidae</td>
<td>A-M88, A01, S44</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpophilus hemipterus (Limaena)</td>
<td>Col.</td>
<td>Nitidulidae</td>
<td>A-M88</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cephalonomia waterstoni (Gahan)</td>
<td>Hym.</td>
<td>Bethylidae</td>
<td>S82</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cercyon cephalonica (Staunton)</td>
<td>Lep.</td>
<td>Pyralidae</td>
<td>R03, A-M88</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptolestes ferrugineus (Stephens)</td>
<td>Col.</td>
<td>Laemophloeidae</td>
<td>A-M88, A01, S44</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptolestes pusillus (Schönherr)</td>
<td>Col.</td>
<td>Laemophloeidae</td>
<td>A-M88, A01, S44</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cynaeus angustus (Grouvelle)</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>A05, N04, S44, R-W47</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimachiodes discolor (Walker)</td>
<td>Lep.</td>
<td>Oecophoridae</td>
<td>R-W47, S82</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diatraea funebris (Fabricius)</td>
<td>Lep.</td>
<td>Pyralidae</td>
<td>S82</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enardis sarcitrella (Zeller)</td>
<td>Lep.</td>
<td>Pyralidae</td>
<td>R-W47, S82</td>
<td>CS4, C54, A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect species</td>
<td>Order Family</td>
<td>Reports by location studied&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>--------------</td>
<td>---------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gnatocerus cornutus</strong> (Fabricius)</td>
<td>Col. Tenebrionidae</td>
<td>W91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Habrobracon hebetor</strong> Say&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Hym. Braconidae</td>
<td>R03, A-M88, A-S06, F09, N04, R-W46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hofmannophila pseudospretella</strong> (Stainton)</td>
<td>Lep. Oecophoridae</td>
<td>R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Holepyris sylvanidis</strong> (Brethes)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Hym. Bethylidae</td>
<td>A-M88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lasioderma serricorne</strong> (Fabricius)</td>
<td>Col. Anobiidae</td>
<td>W91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Latheticus oryzae</strong> Waterhouse</td>
<td>Col. Tenebrionidae</td>
<td>A-M88, A01, W85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liposcelis bostrychophila</strong> Badonnel</td>
<td>Pso. Liposcelidae</td>
<td>W91, R94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liposcelis decolor</strong> (Pearman)</td>
<td>Pso. Liposcelidae</td>
<td>R94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liposcelis entomophila</strong> (Enderlein)</td>
<td>Pso. Liposcelidae</td>
<td>W91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lispe uliginosa</strong> (Fallen)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Dip. Anthomyiidae</td>
<td>R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lytocoris campestris</strong> (Fabricius)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Hem. Anthocoridae</td>
<td>N04, P-P95, R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mycetophagus quadriguttatus</strong> P. Muller</td>
<td>Col. Mycetophagidae</td>
<td>C54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nemapogon granella</strong> (Linnaeus)</td>
<td>Lep. Tineidae</td>
<td>C54, R-W47, N04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Oryzaephilus surinamensis</strong> (Linnaeus)</td>
<td>Col. Silvanidae</td>
<td>C54, A-M88, A01, A03, A05, N04, S44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Palorus ratzeburgii</strong> (Wissmann)</td>
<td>Col. Tenebrionidae</td>
<td>D-M98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Palorus subdepressus</strong> (Wollaston)</td>
<td>Col. Tenebrionidae</td>
<td>S85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plodia interpunctella</strong> (Hübner)</td>
<td>Lep. Pyralidae</td>
<td>A-M88, A01, A03, A05, N04, S44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ptinus fur</strong> (Linnaeus)</td>
<td>Col. Ptinidae</td>
<td>C54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ptinus ocellus</strong> W. J. Brown</td>
<td>Col. Ptinidae</td>
<td>R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pyralis farinalis</strong> Linnaeus</td>
<td>Lep. Pyralidae</td>
<td>C54, R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rhyzopertha dominica</strong> (Fabricius)</td>
<td>Col. Bostrichidae</td>
<td>R03, W91, A01, A03, A05, F04, F07, P04, S82, W85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scenopinus fenestratis</strong> (Linnaeus)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>Dip. Scenopinidae</td>
<td>C54, R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect species</td>
<td>Order</td>
<td>Family</td>
<td>Reports by location studied</td>
<td>Grain in bins</td>
<td>Grain in flat storages</td>
<td>Outside*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
<td>--------</td>
<td>-----------------------------</td>
<td>---------------</td>
<td>-----------------------</td>
<td>---------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitophilus granarius (Linnaeus)</td>
<td>Col.</td>
<td>Curculionidae</td>
<td>Hagstrum et al., 2008 (H08)</td>
<td>C53, S59, W46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitophilus oryzae (Linnaeus)</td>
<td>Col.</td>
<td>Curculionidae</td>
<td>Arthur et al., 2006 (A06)</td>
<td>A01, R-W47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitophilus zeamais Motschulsky</td>
<td>Col.</td>
<td>Curculionidae</td>
<td>Flinn et al., 2007b (F07)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitotroga cerealella (Olivier)</td>
<td>Lep.</td>
<td>Gelechiidae</td>
<td>Richardson et al., 2003 (R03)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenebrio molitor (Linnaeus)</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>Flinn et al., 2007b (F07)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenebroides mauritanicus (Linnaeus)</td>
<td>Col.</td>
<td>Trogositidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theocolax elegans (Westwood)*</td>
<td>Hym.</td>
<td>Pteromalidae</td>
<td>Athanassiou et al., 2001 (A01)</td>
<td>A03, A05, N04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tribolium audax Halstead</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>Flinn et al., 2007b (F07)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tribolium castaneum (Herbst)</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>Chao et al., 2005 (C53)</td>
<td>A03, A05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tribolium confusum Jacquelin du Val</td>
<td>Col.</td>
<td>Tenebrionidae</td>
<td>Flinn et al., 2007b (F07)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trogoderma granarium Everts</td>
<td>Col.</td>
<td>Dermestidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trogoderma inclusum LeConte</td>
<td>Col.</td>
<td>Dermestidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trogoderma simplex Jayne</td>
<td>Col.</td>
<td>Dermestidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typhaea stercorea (Linnaeus)</td>
<td>Col.</td>
<td>Mycetophagidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venturia canescens (Gravenhorst)*</td>
<td>Hym.</td>
<td>Ichneumonidae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylocoris flavipes (Reuter)*</td>
<td>Hem.</td>
<td>Anthocoridae</td>
<td>Subramanyam and Nelson, 1999 (S-N99)</td>
<td>A03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Parasites and predators marked with asterisk.

This column includes references to insects found outside bins at elevator, outside elevators or outside flat storages.
ied seasonal changes in populations of three moth species (*Endrosis sarcitrella* (L.), *Ephestia kuehniella* Zeller and *Hofmannophila pseudospretella* (Stainton)) at a Scottish port silo using adult and larval traps. Larval diapause was an important part of the population dynamics of *E. kuehniella*.

Sampling grain for insects with a vacuum probe is currently the best method to identify the bins that need to be fumigated early in the storage period (Reed *et al.*, 2001; Flinn *et al.*, 2003a,b, 2007a). Vacuum probe sampling of grain stored in bins at elevators for insects cost US $0.0094 per bushel of grain (Adam *et al.*, 2010). Because of the low cost of sampling, this cost can easily be recovered as a result of fewer bins being fumigated and fewer grain shipments being rejected because of insects.

The primary insect pests of wheat stored in concrete bins in Kansas and Oklahoma were *R. dominica*, *Cryptoletes ferrugineus* (Stephens), *Sitophilus oryzae* (Linnaeus), *T. castaneum* and *Oryzaephilus surinamensis* (Linnaeus). *R. dominica* causes the most damage, because larvae feed within wheat kernels and adults tunnel through kernels. Their internal feeding results in *R. dominica* and *S. oryzae* being the largest contributor to insect fragments in flour when infested wheat is milled. The growth rate of *R. dominica* in elevator bins has been studied using a vacuum probe to sample grain without moving it (Flinn *et al.*, 2004). Sampling wheat with a vacuum probe at elevators in Kansas and Oklahoma has shown that insect populations increased from June to October, then leveled off and declined as fall and winter temperatures cooled the grain.

Beetles are highly mobile, and the numbers of each insect species in a grain sample depends upon their preference for favorable micro-environmental conditions and possibly intra- and interspecific associations. The number of *T. castaneum* in a grain sample increased as the number of *R. dominica* in-
creased, but the number \textit{C. ferrugineus} was not correlated with the number of \textit{R. dominica} (Nansen et al., 2009). The densities of both \textit{T. castaneum} and \textit{R. dominica} decreased as the number of \textit{C. ferrugineus} increased. \textit{C. ferrugineus} and \textit{T. castaneum} can be predators and the species composition of a volume of grain taken as a sample may have been modified by predation. As \textit{T. castaneum} populations increased, so did \textit{R. dominica} but not \textit{C. ferrugineus}.

**BIN-TO-BIN VARIATION**

From June until October less than 20\% of the bins had economically significant insect densities (> 2 insects/kg) (Fig. 2) and generally the bins that had high insect densities (> 5 insects/kg) were located close to other highly infested bins (Fig. 3) (Flinn et al., 2009). This is probably a result of the immigration of insects between bins decreasing with distance away from the infested bin.

**DEPTH DISTRIBUTION**

Vertical distribution of insects in grain stored in elevator bins has been reported by Mahmood et al. (1996), Reed et al. (2001, 2003) and Flinn et al. (2003a,b, 2004, 2009). The numbers of insects generally tended to decrease with the depth below the grain surface suggesting that insects infested wheat stored at the elevator after it had been loaded into bins and then disperse down into the grain. Because more than 90\% of insects are found in the top 12 m of grain, sampling this grain provided a good indication of whether a bin needed to be fumigated (Reed et al., 2001). In the top 0 to 3.7 m of grain, \textit{R. dominica} were 44.2\% of insects in grain samples, \textit{C. ferrugineus} were 35.7\% of insects and \textit{T. castaneum} were 19.0\% (Flinn et al., 2009). From 3.8 to 12.2 m, \textit{R. dominica} were 83.5\% of insects in grain samples \textit{C. ferrugineus} were 7.5\% and \textit{T. castaneum} were 7.7\%.

**INSECTS SHIPPED WITH GRAIN**

Insect infestations in grain being loaded into railcars or received at terminal or mill elevators have been studied. \textit{C. ferrugineus} were found in 38\% of railcars loaded in 1977 and 53\% of the railcars loaded in 1978 (Smith, 1985). Only 6\% of the infestations discovered by intensive sampling as these railcars

![Fig. 2. Percentage of bins with insects detected in grain samples and bins with insect densities high enough to require fumigation (> 2 insects/kg) (From Flinn et al., 2009).]
were loaded were discovered by less intensive sampling by inspectors at terminal elevators as these railcars were unloaded (Smith and Loschiavo, 1978). At an elevator in Kansas, intensive sampling of wheat loaded into railcars found an average density of 2.1 insects/kg (insect densities in half of the railcars are likely to be above the average and those in the other half are likely to be below the average), but official grain inspectors with less intensive sampling underestimated populations in 36 railcars and graded only 14 out of 100 railcars as infested (Hagstrum et al., 2008). Based upon a request for a second official inspection of the grain in the 14 railcars previously graded infested, this grain was then certified to be uninfested.

Sampling only adults greatly underestimated the total number of insects in hopper cars delivering grain to mill elevators (Perez-Mendoza et al., 2004). Immature stages were more abundant than adults. Adults sieved from grain samples and counted were only 2% of the *R. dominica* population, and 5% of the *C. ferrugineus* population. These adult numbers did not differ significantly among hopper cars, compartments in a hopper car or depths in a hopper car. However, the number of immatures did differ significantly among hopper cars and compartments, but

---

**Fig. 3.** Number of bins with high insect densities (> 2 beetles/kg) and distance (number of intervening bins) between the high insect density bin and other high insect density bins (From Flinn et al., 2009).
not depth. The number of insects in grain samples was not correlated with the number of insect damaged kernels (IDK). IDK equals the cumulative number of adults emerging from kernels and often is not equal to the current number of live adults that are present in grain samples. Vacuum probe samples provided a better estimate of insect infestation than sampling the first grain discharged from the hopper.

Joffe (1963) found that moving and cleaning maize every two weeks greatly reduced insect infestations at two elevators, probably in part a result of impact killing insects. The moved and cleaned grain had only 11–26% as many insects as the undisturbed grain. Although moving and cleaning grain just to reduce the insect population may not be practical, recognizing that the insect population is reduced when grain is moved for other reasons is important. Rees et al. (1994) found that only a fifth of C. ferrugineus and a third of Liposcelis spp. survived after moving grain at an elevator. Moving grain to railcars might be expected to result in similar insect mortality. Bryan and Elvidge (1977) found that pneumatic conveying systems at elevators carrying grain samples to grain quality laboratories reduced the number of insects in grain samples that were alive. This is important because only live insects are considered in determining whether grain is given “infested” designation on the grade certificate.

Studies by Barak and Harein (1981) and Reed et al. (1989) have questioned whether the penalties for delivering insect infested grain to elevators are consistent enough or sufficient to encourage good insect pest management. Low-test weight (weight of a bushel of wheat in pounds) was the primary reason that wheat delivered by farmers to the elevator was discounted. Wheat with high-test weight was less likely to be discounted for insects than wheat with a lower test weight. Large lots of grain were more likely to be discounted than small lots because small lots could be blended with other grain without measurably changing the overall quality of grain at an elevator.

**RESIDUAL INFESTATION**

Residual insect infestations in empty bins or outside bins at elevators, and insects flying outside elevators have been studied. Chao (1954) found 26 insect species at three-grain elevators in Washington and Dowdy and McGAughey (1998) found 15 insect species at four-grain elevators in Kansas (Table 1). In a recently decommissioned terminal elevator in Australia, Wright (1991) identified five insect species in empty bins that had been cleaned. Triplehorn (1965) sampled the grain residues at 118 feed mills and grain elevators in Ohio, but he combined the insect data for the mills with the insect data for the elevators. Insects were found at all establishments and the 44 species found at these establishments represented 21 families and 5 orders. Prevalence ranged from finding Attagenus unicolor (Brahm) at 110 establishments to finding some species at only one establishment.

At grain elevators, the species composition in grain residues differed from that in the wheat stored in bins (Reed et al., 2003; Arthur et al., 2006; Hagstrum et al., 2008). R. dominica density was low in grain residues outside bins, grain residues in empty bins and the first grain passing through discharge spout, but the density of this species was high in wheat stored in bins. S. oryzae populations were low in the wheat stored in bins, but populations of this species were high in grain residues outside bins, grain residue in empty bins and the first grain passing through discharge spout. Insect densities in the more accessible grain residues inside empty bins, grain residue in empty bins and the first grain passing through discharge spout were ten times higher than those in the wheat stored in bins. The large numbers of insects in the first grain leaving the discharge spout is likely to be the result of insects from grain residues in empty bins infesting grain stored near the bottom of the bin.

Cleaning the empty bins before refilling resulted in a lower insect density in the discharge spout sample for a period of up to three months after new grain was stored in these bins (Reed et al., 2003). Insect densities in grain residues outside bins were higher in samples collected at the ground or subterranean level (discharge spouts, residues in empty bins, and spills in the basement or tunnel) than at
Fig. 4. Population trends for 4 insect species in wheat and corn in 5 flat storages in Kansas.
the top of the elevator where much of the grain
being conveyed was new grain being loaded into
bins (Arthur et al., 2006). Investigators concluded
that resident populations of stored-grain insects at
elevators should be greatly reduced by routine san-
itation practices such as prompt clean-up of spills,
thorough cleaning of empty bins, and periodic flush-
ing of discharge spouts.
Subramanyam and Nelson (1999) found that
many T. castaneum from an elevator in Minnesota
were dispersing into nearby neighborhood and es-
tablishing residual infestations there. Fields et al.
(1993) trapped R. dominica outside elevators, al-
though sustained infestations of this species have
not been found in stored grain in Canada.

NATURAL ENEMIES
Hymenopteran parasitoids were found in the
wheat stored in bins at 13 out of 16 elevators in
Kansas (Reed et al., 2003). Cephalonomia
waterstoni (Ashmead), a parasitoid of C. ferrugineus,
were most prevalent in grain samples from wheat
stored in bins or grain residues in empty bins, while
Anisopteromalus calandrae (Howard), a parasitoid
of S. oryzae, were most prevalent in samples from
grain residues found outside bins (Arthur et al.,
2006). Theocolax elegans (Westwood), a parasitoid
of R. dominica, and Habrobracon hebetor Say, a
parasitoid of Plodia interpunctella (Hübner) were
found in much smaller numbers. At nine elevators,
parasitoids were found in the grain residue samples
outside bins, and at any one elevator, they were found
in 1.6–9.4% of the grain samples.

INSECT PEST MANAGEMENT
Bridgeman and Collins (1994) describe an area-

Fig. 5. Effects of temperature and moisture on the predicted growth of Rhizopertha dominica populations.
FGIS = Federal Grain Inspection Service (From Hagstrum et al., 1996).
wide insect pest management program in Australia aimed at improving sanitation and switching from using residual insecticides as protectants to fumigation. Managers had become complacent and sanitation had gradually declined. Insects had become resistant to residual insecticides. Written standards were developed for sanitation programs and additional sealing was done to improve fumigation. The percentage of facilities infested was reduced from 60 to 16. The facilities with grain free of insecticide increased from 30 to 90%. Pest management cost decreased from Aus $ 1.50 to 0.60/t.

Questionnaires have been used to characterize insect pest management programs at elevators storing barley (Gardner et al., 1988) and wheat (Cuperus et al., 1990; Kenkel et al., 1993; Martin et al., 1997). Hagstrum et al. (1999) reviewed the information available on managing insect infestations in wheat stored on farm and at elevator. DeLucca et al. (1982) found Bacillus thuringiensis Berliner in 55% of settled grain dust samples and 16% of the respirable dust samples from elevators along the Mississippi river near New Orleans, Louisiana. Harris et al. (1952) found that cleaning wheat reduced average insect density from 4.3 to 3 insects per 100 grams. Harris et al. (1953) found that cleaning corn reduced the average insect density from 7 to 5.1 insects per 100 grams. Storey et al. (1982b) surveyed for malathion residues on grain exported from the United States and found biologically active residues on only 28% of wheat samples and 8% of corn samples. In more recent survey (Subramanyam 2003), phosphine was applied to 11.5%, malathion to 1.5%, chlorpyrifos-methyl to 1.4%, methyl bromide to 0.4%, and diatomaceous earth to 0.2% of wheat stored at elevators. Lindane was applied to 0.2% as a seed treatment. Wright (1991) studied the efficacy of diatomaceous earth as an empty bin treatment for managing psocid populations.

Decision support software (Stored Grain Advisor Pro, http://ars.usda.gov/npa/gmprc/bru/sga Flinn et al., 2007b) developed for wheat stored at elevators uses information on insect density from vacuum probe grain samples taken every 6 weeks to make pest management decisions. Predicted increases in insect density in a 30-day period are estimated using the following equation:

\[
Z = \frac{(9.2004 - 1.6898X + 0.0787X^2 - 0.0011X^3 + 0.1841Y)}{(1 - 0.0197X - 0.0161Y)}
\]

where Z is the rate of increase over 30 days, X is temperature in degrees Celsius, and Y is moisture content in per cent dry weight of the grain basis. The equation works reliably between the range of 20–34°C and 10–13% grain moisture content. Risk analysis is presented graphically to the elevator manager as a bin layout diagram. Stored Grain Advisor Pro accurately predicted which bins would remain safe, and only failed to predict when grain was at a high risk for only 2 out of 533 bins at 28 elevators in Kansas and Oklahoma, and in both cases the insect density was high only near the grain surface suggesting recent insect immigration. With vacuum probe sampling of all bins and this decision support software, a private consulting company, Precision Grain Management (http://www.grainstoragescience.com) has provided scouting services to more than 70 elevators in Kansas, Oklahoma and Nebraska from 2003 to 2010. The sampling program has improved insect pest management by ensuring that fumigation is done at a time when it is most cost-effective.

STEEL BINS AND FLAT STORAGE AT ELEVATORS

In addition to concrete bins, some elevators have large round metal bins and flat storage buildings. Metal bins or flat storage are cheaper to build than concrete bins, but less convenient for loading and unloading grain. For wheat stored in the USA, Kenkel et al. (1993) reported 27% was in metal bins, 26% in flat storages and 47% in concrete bins, and Martin et al. (1997) reported 38% in metal bins, 7% in flat storages, 51% in concrete bins and 4% in wooden bins. Kenkel et al. (1993) considered only hard red winter wheat, while Martin et al. (1997) considered this and several other varieties. Gates (1995) studied population dynamics of R. dominica, C. ferrugineus and its parasitoid, C. waterstoni, in steel bins at two elevators in Oklahoma during two years. Gates concluded that parasitoid populations often peaked 1 or 2 weeks after the host populations
and reduced *C. ferrugineus* population. Nansen et al. (2004a) studied the flight activity of *C. ferrugineus* adults outside steel bins at elevators in Oklahoma and developed equations to predict the effect of temperature on insect flight activity. Gates (1995) studied the flight activity of *C. ferrugineus, C. waterstoni, R. dominica* and *Typhaea stercorea* (L.) outside steel bins. Flight traps detected insects well before grain was binned. More *R. dominica* were captured by flight traps outside bins than those inside. Barrer (1983) found that several species of stored-product insects (see Table 1) were attracted to the odors from sealed earth-walled flat wheat storages in Australia and could enter through small holes in the plastic covers.

Insect species composition, distribution and abundance have been studied in flat storages of barley and sorghum in Arizona (Nutting and Gerhardt, 1964), of maize in Wisconsin (Nansen et al., 2004b,c; Parajulee and Phillips, 1995) and Georgia (Arbogast and Mullen, 1988), and of wheat in Australia (White, 1988), Canada (Smallman, 1944), England (Richards and Waloff, 1946, 1947; Waloff and Richards, 1946; Wakefield and Cogan, 1999) and Greece (Athanassiou et al., 2001, 2003, 2005; Athanassiou and Saitanis, 2006). Insect populations increased during storage and insect densities decreased with depth below the grain surface as with grain stored in concrete bins. Nutting and Gerhardt (1964) only reported on *Trogoderma granarium* Everts populations. *P. interpunctella* and *Sitophilus zeamais* (Motsch.) were the main pests of stored maize. The four primary pests of wheat stored in concrete bins were also common in flat storage.

![Graph](image)

**Fig. 6.** Variation in population estimates in relation to the number of samples (From Hagstrum and Flinn, 1992).
Canada, *C. ferrugineus* and *P. interpunctella* were the main insect problems in flat storage. *P. interpunctella* was mainly a problem near surface, but could reach depths of 1.2–1.8 m near posts and walls. A scouting program was initiated to regularly sample flat storages. An additional two species of pyralid moths (*Ephestia elutella* (Hübner) and *E. kuehniella*) infesting wheat in flat storage have been studied. For studies considering more than one species, totals of 2 to 16 insect species infesting grain in flat storages were identified in any one study (see Table 1). These species include the natural enemies, *A. calandrae*, *C. waterstoni*, *H. hebetor* and *T. elegans*, that also have been reported for concrete elevator bins, and the natural enemies, *Dimachus discolor* (Walker), *Holepyris sylvanidis* Brethes, *Lyctocoris campestris* (Fabricius), *Scenopinus fenestralis* (L.), *Venturia canescens* (Gravenhorst) and *Xylocoris flavipes* (Reuter), that probably occur in concrete elevator bins, but have not been reported.

Insect populations in 25 flat storages of corn or wheat at elevators in Kansas were sampled 116 times between 2003 and 2009 by the consulting firm, Precision Grain Management. A total of 16,549 grain samples of 3 kg each were taken or an average of 143 samples per visit. The samples were often taken after aeration and fumigation to assure the elevator manager that their pest management had been effective. Except for one wheat sample with 22 *T. castaneum* and another with 30 *C. ferrugineus*, > 100 *R. dominica* and > 100 *T. castaneum*, only 44 insects were found in concrete elevator bins, but have not been reported.

Insect populations in 25 flat storages of corn or wheat at elevators in Kansas were sampled 116 times between 2003 and 2009 by the consulting firm, Precision Grain Management. A total of 16,549 grain samples of 3 kg each were taken or an average of 143 samples per visit. The samples were often taken after aeration and fumigation to assure the elevator manager that their pest management had been effective. Except for one wheat sample with 22 *T. castaneum* and another with 30 *C. ferrugineus*, > 100 *R. dominica* and > 100 *T. castaneum*, only 44 insects were found in the other 9122 samples taken during 68 visits to 20 of the flat storages. Both of these high insect density samples were taken from the top 1.2 m of grain. Pest management practices generally were very effective for these flat storages.

The other 5 flat storages that were sampled 48 times often had higher insect populations (Fig. 4). Overall for corn, 90.9% of the insects were *Sitophilus* spp., 7.3% were *T. castaneum*, 0.7% were *R. dominica* and 1.1% were *C. ferrugineus*. For wheat, 74.7% of the insects were *Sitophilus* spp., 17.0% were *R. dominica*, 6.1% were *T. castaneum* and 2.2% were *C. ferrugineus*. Insect populations in wheat generally peaked in March and then declined. Insect populations in corn generally peaked in June and then decreased. The insect populations in the grain generally did not reach densities which would result in an infested designation on the grade certificate.

**SIMILARITIES OF INSECT ECOLOGY IN ELEVATOR BINS TO THAT IN FARM BINS**

In general insects were highest in the top layers of grain in elevator bins and decreased with grain depth, as has been observed on farms (Hagstrum, 1989). This indicates that insects are entering the grain mass through the top of the grain bin either through the grain-loading hatch or through bin vents at the top of the bin, as with farm storage (Hagstrum, 2000). A simulation model of *R. dominica* population growth on farms predicted insect densities at elevators very well when the immigration rate was increased by 50% (Flinn et al., 2004). This suggests that simulation studies by Flinn and Hagstrum (1990), Flinn et al. (1997) and Hagstrum and Flinn (1990) may be useful at elevators. These studies showed that lowering the grain temperature or moisture content reduced insect population growth rate (Fig. 5). Given the similarity of insect ecology in concrete elevator bins to that in farm bin, sticky traps may be useful in the head house at grain elevator in locating infested bins, because they correctly predicted whether *R. dominica* was present in 78.6% of farm bins and whether *C. ferrugineus* was present in 85.8% of farm bins (Hagstrum et al., 1994). Location of insect infested bins involves putting out an array of traps and sampling the bins closest to the traps with the highest trap catch.

**ECOLOGY UNDERLYING PEST MANAGEMENT**

Seven examples of the importance of insect ecology to pest management and marketing decisions are considered here, i.e., insect monitoring, grain segregation and drying, sanitation, grain blending, aeration, fumigation and grain marketing.

Insect distribution determines the number of samples needed to make pest management and marketing decisions. Taking a single sample when grain
is received at an elevator provides adequate information for grain grading because quality factors often may not vary much between locations in grain mass. However, insects are mobile and their densities do vary between locations. A single 1-kg sample generally estimates an insect density of 2 insects/kg within ± 2 insects/kg (Fig. 6). This means that with an average density of 2 insects/kg the actual number of insects in a single 1-kg sample can be as low as zero, as high as four or anywhere in between. The graph shows that increasing the number of samples provides a much more accurate estimate of the actual average insect density in a grain bin.

Grain is segregated by moisture content and high moisture grain is dried to avoid mold-induced hot spots and to avoid penalties for excessive moisture when grain is shipped. This also is an ecologically-based management practice for insects because drying grain reduces insect population growth (Fig. 5).

A good sanitation program can reduce the overall insect infestation at an elevator. Insects are highly mobile and grain residues inside and outside bins at an elevator are a common source of the insects that infest other stored grain. Cleaning empty bins before adding new grain, flushing discharge spouts after storing new grain, prompt removal of grain residues outside the bins and disposal of the residual grain in such a manner that insects cannot reenter an elevator can reduce the extent of insect infestation.

Delaying the blending of grain as long as possible or blending when grain is unloaded from bins are ecologically-based insect pest management practices that can minimize the amount of grain infested. Blending may combine infested and uninfested grain increasing the amount of insect infested grain. In bins that had received wheat at harvest time, the wheat between 12 m below the surface and a meter up from the bottom was generally inaccessible to insects until the grain was moved. Blending will tend to move insects lower down in the grain mass increasing the amount of grain that is insect infested. The grain near the bottom of bin is discharged first. In tall bins, mass flow, with every kernel moving towards the discharge spout at the same velocity, continues until the distance between the grain surface and bin floor is 1.5 to 3.5 times the bin diameter (Reed, 2006). During this time, grain from the source bin will be added to the receiving bin without changing insect depth distribution. However, the flow pattern converts to funnel flow when the distance between the grain surface and bin floor is 1.5 to 3.5 times the bin diameter and then only the grain directly above the discharge spout and a thin layer from the grain surface are in motion. During this time, grain from the top surface and directly above discharge spout of the source bin will be added to the receiving bin first resulting in some changes in the depth distribution of insects.

Because insect development and survival are influenced by temperature, aeration can be used in two ways. Early summer aeration during the coldest hours of the night can slow insect population growth by reducing grain temperature by a few degrees (Fig. 5). Fall aeration can kill insects when grain temperature is reduced to 15–20ºC for several months (Hagstrum and Flinn, 1994).

Insect ecology impacts fumigation efficacy in three ways. First, insect densities are highest near the surface where retention of the fumigant is most difficult. This makes the relationship between grain temperature, outside air temperature and the distribution of aluminum phosphide pellets in the bin particularly important (Flinn et al., 2007c; Flinn and Reed, 2008). Second, the seasonal trends in insect numbers are important in determining the optimal timing of fumigation. Pest management decisions should be based upon grain sampling, because generally only a small portion of the bins at an elevator need fumigation at any time (Fig. 2). Delaying fumigation as long as possible can reduce the need for additional fumigation because cool fall temperatures subsequent to fumigation can reduce insect population growth rate. Third, discovering and re-fumigating bins in which fumigation was unsuccessful is important in preventing immigrants from these bins from infesting nearby bins (Fig. 3).

Knowing insect infestation levels can be important for profitable grain marketing. If too many insects are found, grain may be rejected by the buyer, and the seller may have to find a new buyer, pay for
additional shipping and pay to have the grain fumigated. When the depth distribution of the insect populations is determined by vacuum probe sampling, the insect density in the grain unloaded from bin can be predicted. Because of residual insect infestations, a small amount of the very first grain out of bins may have higher insect densities. However, insect densities then should be low until grain shifts from mass flow to funnel flow. Funnel flow will result in grain from the surface with high insect densities being unloaded from the bin.

Ecologically-based insect pest management can take advantage of insect vulnerabilities to develop cost-effectiveness methods. Given the variability between bins, each bin or a cluster of bins may require a different insect pest management program. Delaying blending as long as possible will be advantageous in minimizing the amount of grain at an elevator that is infested by insects. Delaying fumigation until fall can minimize insect population growth and fumigation cost at an elevator because cooler fall temperatures can result in lower insect population growth following fumigation and thus eliminates the need for another fumigation.

Acknowledgement. We are grateful to Dr. George Opit for reviewing this manuscript.

REFERENCES


Wright, E.J. (1991) A trapping method to evaluate effi-

Accepted 25 May 2010