# SEASONAL ACTIVITY OF INSECTS TRAPPED IN STORED WHEAT IN KANSAS AND STORED RICE IN TEXAS

by

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# Abstract

Knowing the factors that influence the distribution patterns, establishment and persistence of stored product insects aids in the development of a more effective pest management program in grain storage structures. This research focuses mainly on the insect communities of stored wheat and stored rice in two different geographical locations, their temporal relationships and the most important or abundant species within that community. Stored wheat was sampled for one season in Manhattan, KS and for rice stored in Beaumont, TX was sampled for two seasons. Hairy fungus beetle, *Typhaea stercorea* (Coleoptera: Mycetophagidae) was one of the most abundant species and was present in every bin of either wheat or rice and appeared to move into and out of the grain mass. In wheat bin, Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae) was a predominant species captured in the bin headspace, but was not frequently recovered in the grain mass. Headspace temperatures tended to be warmer than grain temperatures and outside temperatures. Other major insects recovered in wheat bin included the following groups or species: Anthicidae, Lathridiidae, *Cryptolestes*, foreign grain beetle *Ahasverus advena* (Coleoptera: Silvanidae), sawtoothed grain beetle *Oryzaephilus surinamensis* (Coleoptera: Silvanidae), red flour beetle *Tribolium castaneum* (Coleoptera: Tenebrionidae), smalleyed flour beetle (Coleoptera: Tenebrionoidea) and minute pirate bug *Xylocoris favipes* (Hemiptera: Anthocoridae). In rice bins, the predominate species were hairy fungus beetle, foreign grain beetle and Angoumois grain moth *Sitotroga cerealella* (Lepidoptera: Gelechiidae). Angoumois grain moth was one of the most abundant species in rice, and was captured in the headspace as well as below the grain surface. Rice bins varied considerably in the relative abundance of different species between bins within a season and between seasons. Foreign grain beetle and hairy fungus beetle were especially variable among

bins. Two species of weevil (Coleoptera: Curculionidae) that are not grain pests, the sugar cane rootstock weevil, *Apinocis deplanata* and rice water weevil, *Lissorhoptrus oryzophilus* (Coleoptera: Curculionidae), were present in high numbers in rice bins from September-December 2009.

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# Chapter 1 - Introduction

The focus of this thesis is to provide additional understanding of behavior and ecology of stored-product insect pests associated stored wheat and stored rice. There are approximately 1,660 species of insect associated with stored-products (Hagstrum and Subramanyam 2009). These species include fungivores, granivores, omnivores and natural enemies distributed across the orders Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera and Psocoptera. There is an increasing demand by the general public for decreased use of pesticides and also for increased food production and food quality as the world population continues to grow. Stored-product pests can account for up to 10 percent of loss of stored grains in developed countries and 20 percent or more loss of stored grains in developing countries (Pimentel 1991). Because of potential for economic damage cause by stored product insects, there is a growing need for better understanding of not only behavior of stored product insects but also their ecology to be used in developing better and safer pest management.

Stored-product pests can infest grain at some points during pre-harvest and most all post-harvest contexts during transportation, storage, processing and marketing (Tigar et al. 1994, Hagstrum and Flinn 1995, Arbogast and Throne 1997, Roesli et al. 2003, Perez-Mendoza et al. 2004). Management of stored grain insect pests by farmers or elevator managers should be based upon knowledge of the grain storage environment and the ecology of insect pests. Grain storage facilities and practices, geographical location, government policies and marketing demands for grain quality are discussed as factors influencing stored grain insect pest management decisions (Hagstrum et al. 1999). Knowledge of sources of insect infestation, population dynamics, and movement of pests is needed to effectively target and use both conventional and alternative pest management tactics (Dowdy 1998). Stored-product insects can be classified as “internal feeders” if they exploit whole kernels of grain with most or all of the larval feeding occurring inside the seed (e.g., granary weevil, *Sitophilus granarius* (L.); rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae); lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae), and Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelichiidae)) or classified as "external feeders" if they utilize cracked or damaged kernels, grain dust, and grain debris and are unable to penetrate the seed coat (e.g., Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae); sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae); red flour beetle, *Tribolium castaneum* (Herbst); confused flour beetles, *T. confusum* Jacquelin du Val (Coleoptera: Tenebrionidae); flat grain beetle, *Cryptolestes pusillus* (Schönherr) (Coleoptera: Silvanidae); and cadelle beetles, *Tenebroides mauritanicus* (L.) (Coleoptera: Tenebrionidae)). Other species, such as the foreign grain beetle, *Ahasverus advena* (Waltl) (Coleoptera: Silvanidae), and hairy fungus beetle, *Typhaea stercorea* (L.) (Coleoptera: Mycetophagidae), are found associated with grain but tend to feed on molds or fungi growing on grain (David et al. 1974, Shayesteh et al. 1974).

One of the most damaging insect pests of stored wheat and stored rice in the United States is the lesser grain borer because both larvae and adults can damage kernels. Lesser grain borer can also cause localized increases in heat and moisture that lead to accelerated mold growth (Hagstrum et al. 1999). Insect infestations are common in farm-stored wheat in the United States (Storey et al. 1983). More recent studies have shown that insect densities were lower when newly harvested wheat was stored for less than one year (Hagstrum 1987, 1989). In contrast to perishable commodities and finished foods, wheat is usually stored during most of the year at near ambient temperatures. Low temperatures reduce insect development and thus lengthen the time before populations increase to a point where they cause significant damage (Banks and Fields 1995).

Post-harvest losses to grain during storage can be up to 10%, depending on the type of grain stored, pest species involved, and location and type of the storage system (Cao et al. 2002**)**. In most developed countries, the quality standards that have been developed resulted in a very low tolerance of insects. Even one live insect can result in rejection of shipment and trigger the need to fumigate, which can result in a serious loss of revenue. In processed commodities, costs due to stored-product insect damage are usually not from direct damage, but can still result from an increased need for sanitation and chemical treatments, loss of consumer confidence, public health issues associated with allergens in food, and consequences of unsatisfactory food safety inspections (Campbell et al. 2002).

Flight activity of insects outside bins and their immigration into bins are important factors to consider in managing insect pests. Newly harvested wheat generally becomes infested after being stored in a bin (Hagstrum 2000; Vela-Coiffier et al. 1997). Because the number of insects migrating into a bin influences the level of insect infestation, estimates of insect immigration rates are needed to accurately forecast insect infestation levels using computer. In another experiment measuring flight activity, adult insects entering 34 bins storing newly harvested hard red winter red wheat on 12 Kansas farms were sampled from July through December 1998 using ventilation traps. Ventilation traps provided a more direct measure than probe traps of the total numbers of insects entering bins storing newly harvested wheat. Bin size did not influence ventilation trap catch but as many as a third more insects may immigrate into large bins at the eaves compared with small bins because of their larger circumference (Hagstrum 2000). Studies by Hagstrum (1989), Dowdy and McGaughey (1994), and

Hagstrum et al. (1998) have shown that wheat is generally uninfested after it goes into storage, and Hagstrum (1989) showed that *Cryptolestes ferrugineus* (S) (Coleoptera: Laemophloeidae) infested the upper grain layer during the first weeks of storage. Thus, infestations by *C. ferrugineus* likely originate from individuals immigrating into grain facilities through ventilation ducts and the openings near the top of the structure shortly after storage and initially infest the upper layer of grain (Nansen et al., 2004).

This thesis will report research done on the community of stored-product insects found in wheat and rice and their patterns of movement into and out of the grain mass as a function of season and temperature. Movement into and out of the grain mass is likely to be influenced by the temperature within the grain and differences in temperature between the grain and the headspace or outside environment. Because of these important factors, my focus of research will be on temperature variance of grain vs. headspace in bins of wheat and rice over time within a storage season and how temperature and time effect stored product insect diversity and activity.

## Wheat and rice storage systems: similarities, differences and the importance of stored product insects.

Rice, *Oryza sativa* (L.) (Poales: Poaceae) and wheat, *Triticum aestevum* (L.) (Cyperales: Poaceae) can be infested by the same group of stored-product pests, but the relative abundance and degree of damage caused can vary between commodities. Rough rice because of the retained husk can be less susceptible to stored product pests (Chanbang et al. 2008). Hard winter red wheat is primarily grown in the central plains area of the U.S. from North Dakota down to Texas as well as the Mississippi delta area of Missouri, Arkansas and Louisiana. Rice is primarily grown in two distinct regions, northern California and in the south east along the Gulf coast and up along the Mississippi river (Texas, Louisiana, Mississippi, Arkansas, and Missouri). Wheat and rice growing regions overlap only along the Mississippi river. The time of year that both are harvested also varies with winter wheat being harvested in midsummer between June through September while rice is harvested from August through October. The length of time in storage for each commodity is also variable from state to state.. Pests that infest these two commodities overlap. The lesser grain borer, Angoumous grain moth, Indianmeal moth and weevils are important to both grains (Hagstrum and Subramanyam 2009).

Rice grain is hygroscopic and in open storage systems the grain moisture content will eventually equilibrate with the surrounding air. According to the International Rice Research Institute, both wheat and rice should generally be stored at an optimal moisture level of 12-13% (IRRI 2005). High relative humidity and high temperatures contribute to high equilibrium or final moisture content. In many tropical countries, the equilibrium moisture content is above safe storage moisture levels and fungal growth becomes a more critical concern (Mutters et al. 2009). The moisture level is an important factor of storage because insects living in stored rice depend on grain moisture to sustain life (Mutters et al. 2009). The rice moisture range for insect growth is narrow and the rice weevil is unable to reproduce below a grain moisture level of 10 percent and its reproduction rates are maximized at 14 percent. The long term survival of the rice weevil diminishes with decreasing grain moisture content. One method of insect control is to store rice at low moisture content but only for seed rice. Storing milled rice at low humidity levels would place it at risk for fissuring, poor milling yields and lost weight at its time of sale. In commercial practice, rice moisture content is not used to control insects but more reliance is placed on temperature management and sanitation as the primary nonchemical tools for preventing infestations (Mutters and Thompson 2009). Wheat should be stored at 14% moisture or less for 9 months storage and 13% moisture or less for more than 9 months storage (Wilcke et al. 1992).

Temperature in stored wheat and rice is likely to be different due to differences in how the grains pack and the geographic regions in which each commodity is grown. Wheat has a bulk density of 60 pounds in a bushel (test weight) while rice is only 45 pounds in a bushel. Because temperature primarily controls the rate at which insects develop in stored wheat and rice, temperature management is an important consideration when trying to manage stored product insects. The optimal temperature for development of most stored product insects is between 25°-33°C, with lower temperatures reducing insect development rate and prolonging the time before populations increase to a point where they can cause significant damage (Fields 1992). In addition, low temperatures reduce insect movement, reproduction and survival. This study also concluded that larger bins tended to stay warmer longer than smaller bins. Aeration is an important method of reducing grain temperature and thus controlling stored product insects in both wheat and rice. A recent study in rice with a starting grain temperature of 29.4 °C, predicted populations of lesser grain borer to decrease by twofold as aeration increased from 0.79 to and 1.4 $m^3$/min/ton. However, as the starting grain temperatures increased to 32.2°C and 35.0°C increasing aeration airflow rate did not have the same predicted level of population decrease. . Regardless of starting grain temperature or aeration airflow rate, the predicted levels of lesser grain borer in aerated rice did not exceed 75 adults per ton by 31 December, far less than the range of 5,465-11,855 adults per metric ton in unaerated rice (Arthur et al. 2011). Other factors that should be considered besides temperature are species and developmental stage, temperature acclimation, and relative humidity. For instance, the rusty grain beetle, it's most cold hardy stage is the adult stage while for the rice weevil it is the larva. Another study also indicated that very high grain temperatures between 60° and 65° C for a few seconds or minutes could also kill all stored grain insects (Muir et al. 1996). However, these high temperatures can damage the baking quality of wheat.

Insects in grain can actively seek out zones of preferred temperature. A study demonstrated that lesser grain borer in a temperature gradient avoided the highest temperature region (35° to 42°C) and moved toward the more moderate temperature areas of 25° to 32° C (Flinn and Hagstrum 2011)

## Sources of infestation of stored grain

Finding insect infestation sources is important for any pest management program. There can be many sources for stored-product insects entering grain bins, which can be difficult to locate. Sources can include other stored commodities and commodity residues in empty storage bins, throughout processing and marketing facilities as well as in grain residue in transportation vehicles like trucks, rail cars, barges and ship holds. Insects infesting stored commodities and their residues have been proposed to be a more important source of new infestations than insects breeding on wild hosts (Hagstrum et al. 1999).

Residual infestations in storage facilities also pose problems. Only a small layer of grain dust or food residue is necessary for stored product insects to develop, survive and reproduce. Insects infesting food residues in storage, processing and marketing facilities and in transportation vehicles include many stored product insect pest species that are capable of causing significant or extensive damage. Seven species were commonly found in storage processing and retail facilities and in transportation vehicles, these include foreign grain beetle, sawtoothed grain beetle, indianmeal moth, lesser grain borer, cigarette beetle, red flour beetle and the hairy fungus beetle (Hagstrum and Subramanyam 2006).

Flight activity of any insect is an important factor when it comes to dispersal, emigration, and immigration. One important consideration is how outdoor flight activity is affected in relation to weather patterns. One major pest of stored grains for which many studies have been done is the lesser grain borer, which is a major pest of stored grains, especially wheat, rice and sorghum in warmer regions of the world (Haines 1991). Lesser grain borer is a strong flier and extensive trapping studies have shown a characteristic seasonal activity pattern that seems to correlate with weather conditions (Cogburn et al. 1984, Sinclair and Haddrell 1985, Throne and Cline 1994). For instance, lesser grain borer has been trapped in woodlands, miles from grain stores, so it is important to consider habitat and climatic factors that could cause changes in lesser grain borer densities (Cogburn 1988, Edde et al. 2005). Seasonal patterns of outdoor flight activity in insects can by used to predict insect infestations before they occur in grain bins and can also help one make more effective management decisions in timing of insecticide application or when to aerate (Edde et al. 2006).

Most wheat that is newly harvested and freshly loaded into bins is generally un-infested according to a study that was done by Hagstrum (1989) and Dowdy and McGaughey (1994). A study by Hagstrum (1987) also showed that *Cryptolestes ferrugineus* predominantly infested the upper grain layer during the first weeks of storage. In a separate study, done by Nansen et al. (2004), seven trap catch data sets of unbaited sticky trap catches were placed on the outside of grain bins and corresponding probe trap catches were stuck in the upper gradient of the grain mass inside. In late June and July the catches on the unbaited outside traps occurred before catches were recorded in the probe traps within the grain mass approximately 3 days later. In late August catches within the bin continued to increase while outdoor catches decreased. Infestations by *Cryptolestes* spp. likely came from individuals immigrating into the bin via ventilation ducts and other openings near the top of the bin (Nansen et al. 2004).

In a study done by Vela-Coiffier et al. (1995), placement of traps near bin eaves resulted in more insect captures than any other position within the bin. This study also indicated that infestation occurred after the grain was placed in a bin based on increasing numbers of insect captures in probe traps placed in the grain mass with the length of storage time combined with the capture pattern of grain insects by flight traps.

Additionally, a study conducted by Dowdy et al. (1994) on the activity of stored product insects outside farm storage facilities during the first two months of storage helped to explain the relationship between insect densities both inside and outside of the bin. It was shown that for farms with high numbers of stored product insects outside of the grain bins, there were also high numbers of insects inside the experimental bins. However, this relationship was not found in the larger commercial bins, presumably due to the use of insecticide on the grain surface. Grain moisture and the presence of livestock could affect insect numbers in the untreated experimental bins (Dowdy et al. 1994).

## Justification for research

Rice is the major staple crop of nearly half of the world's population, and is particularly important in Asia, where approximately 90% of the worlds rice is produced and consumed (Zeigler and Barlclay 2008, Khush 2004). Global rice production has tripled in the last five decades from 150 million tons in 1960 to 450 million tons in 2011. Rice is a staple food with inelastic demand (Mohanty et al. 2010) and with historically inadequate storage infrastructure in most developing countries in Asia (Rolle 2011). Trends in global rice consumption largely follow those in global production, rising steadily over the last five decades (Rejesus et al. 2012). With the increased demand and rice production in the United States (Batres-Marquez et al. 2009) the amount of research into protecting this stored commodity has not kept pace. Much has been written about wheat stores and the insects that affect wheat, but there is a lesser amount of research and literature about rice stores (Hagstrum and Subramanyam 2006). According to Gary Williams (personal communication) at Texas Agricultural Market Research Center (TAMRC) College Station Texas, the United States is the fifth largest exporter of rice in the world. More research information into stored rice will reduce losses due to insect infestations especially in developing countries where rice is not only a major production crop but also is often stored in inadequate buildings or structures.  Knowing the insect community within stored rice will help develop better control strategies. Comparing wheat and rice can show the differences between the two commodities in storage. I will attempt to fill in some of these data gaps with the research that is described below.

## Objectives

While there is quite a bit of information on insect community in wheat and even some literature on rice, the data gaps are in the seasonal patterns in activity, the relationship with movement into and out of the grain, and seasonal trends in temperature within the grain, and the relationship between temperature and insect immigration and emigration from grain. More specifically, headspace temperatures are rarely measured but could have an important influence on insect movement patterns.  My research aims to fill some of these data gaps and provide a foundation for further analysis. Specifically, my research will address the following:

1. Determine the seasonal patterns in insect species composition in stored wheat and rice.
2. Evaluate seasonal trends in grain and headspace temperature in stored wheat and rice.

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# Chapter 2 - Stored Product Insect Activity in Wheat Bin Grain Mass and Headspace

# Abstract

Insect activity and temperature were monitored for a period of 10 months in Manhattan Kansas USA within a bin of stored winter wheat. The most abundant species captured in the grain mass as measured using probe traps was foreign grain beetle *Ahasverus advena* (Coleoptera: Silvanidae) (54%), hairy fungus beetle, *Typhaea stercorea* (Coleoptera: Mycetophagidae) (27%), *Cryptolestes* spp. (10%) and Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae) (4%). The most abundant species in the headspace as measured using screen traps was Indianmeal moth (78%), hairy fungus beetle (14%), foreign grain beetle (6%) and minute pirate bug *Xylocoris favipes* (Hemiptera: Anthocoridae) (2%). There were total numbers captured in probe traps ranging from 1 to 533 for the ten different species recorded within the grain mass. Temperature in the grain mass and headspace of the storage bin was monitored the entire time and insects counts dwindled as temperature dropped. More research will need to be done to determine if there was a statistically significant correlation between insect activity in the grain mass and headspace and relationship with temperature.

# Introduction

Insect pests infesting stored wheat fall into one of two categories based on their feeding habits, internal and external feeders. Internal feeders are those whose larvae feed on the inside of grain kernels and bore holes through grain such as the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) and the rice weevil *Sitophilus oryzae* (L) (Coleoptera: Curculionidae). Because these two species contribute to the grading factor by creating insect damaged kernels, they are considered serious economic pests. External feeders are unable to penetrate the seed coat either as adults or larvae and live feeding on broken kernels, grain dust, fungi and most forms of milled grain products such as flour or feed. Some important external grain feeders include the rusty grain beetle, *Cryptolestes ferrugineus* (Steph.) (Coleoptera: Laemophloeidae), red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae), hairy fungus beetle, *Typhaea stercorea* (L) (Coleoptera: Mycetophagidae) and Indianmeal moth, *Plodia interpunctella* (H) (Lepidoptera: Pyralidae) (Peairs et al., 2010).

Compared to most other insect habitats, a filled grain silo constitutes a uniform and essentially unlimited food source, which is relatively well protected against diurnal and seasonal fluctuations in weather conditions (Nansen et al., 2009). This is a unique human-made enclosed ecosystem, which may host a wide variety of arthropods and fungi (Barak and Harein, 1982 Subramanyam and Harein, 1990; Hagstrum et al., 1998; Buchelos and Athanassiou, 1999; Athanassiou and Buchelos, 2001; Athanassiou et al., 2001, 2003, 2005; Nansen et al., 2004a; Toews et al., 2005). Insect density can be assessed through direct or indirect sampling techniques (Subramanyam and Hagstrum, 1995). Direct sampling of grain is based on collecting known volumes of grain and collecting insects from those samples (Hagstrum et al., 1998) or larger samples (Flinn et al., 2004). This method provides detailed information about insect density at a given time when the sample was collected, but is quite labor intensive and not always practically feasible. Indirect sampling is based on the use of baited or unbaited traps; and, in bulk stored grain, unbaited perforated probe or pitfall traps with manual counting of insects captured are widely used (Subramanyam and Harein, 1990; Subramanyam and Hagstrum, 1995; Vela-Coiffeir et al., 1997; Hagstrum et al., 1998; Buchelos and Athanassiou, 1999, Athanassiou and Buchelos, 2001; Toews et al., 2005). Generally, insects are detected earlier with probe traps than when the monitoring of grain insects is based upon direct sampling (Subramanyam and Harein, 1990; Subramanyam and Hagstrum, 1995; Hagstrum et al., 1998; Buchelos and Athanassiou, 1999). In addition, probe trap captures may detect the presence of insect species that, at low densities, may go undetected in grain samples (Athanassiou and Buchelos, 2001; Nansen et al., 2004a Towes et al., 2005).

Insects in the grain can originate from the outside. Farms with high numbers of insects outside had high numbers of insects in a 25-bushel experimental bin and farms which had few insects detected outside also had fewer insects in a 25 bushel bin (Dowdy and McGaughey, 1994). There have been various studies about how insects immigrate into bins of newly harvested wheat. Hagstrum (2000) and Vela-Coiffier et al. (1997) showed that eave vents are prime locations for insects to enter bins. Nansen et al. (2004) showed a correlation between insect activity inside and outside of a grain bin. Increasing numbers of insects with depth and length of storage time, combined with the capture pattern of grain insects by flight traps outside, indicate that grain infestations probably occur after binning (Vela-Coiffer et al., 1996). Hagstrum (2000) showed using traps placed in ventilation openings that as many as a third more insects immigrated into large bins at the eaves than other routes of entry. Insects such as foreign grain beetle, hairy fungus beetle and rusty grain beetle increased more than other species detected during the storage period (Hagstrum, 2000).

After insects immigrate into a bin from the eaves, they infest the grain from the surface which should result in a vertical distribution pattern skewed to greater abundance near the surface. A study by Nansen et al. (2004) showed that insect density was significantly higher in top samples compared to bottom samples, with a greater diversity of the species in top samples compared to bottom samples.

Insect traps are effective and sensitive tools for detection of adult insects (Loschiavo, 1974, 1975; Barak and Harein, 1982; Lippert and Hagstrum, 1987). All insect traps depend on insect movement. Any factor that influences insect movement will also affect trap capture. The magnitude of this effect depends primarily on insect species, temperature, grain type and grain condition. Five of the most important variables affecting trap catch are insect species, trapping duration, grain temperature, grain type, condition and trap placement. For example, the number of rusty grain beetle, lesser grain borer, red flour beetle and rice weevil captured per trap increased by 0.35 insect per degree between 10 and 32°C (Cuperus et al., 1990). Insect catches in traps have been found to be significantly greater at higher grain temperatures (Loschiavo and Smith, 1986; White and Loschiavo, 1986; Fargo et al., 1989). Aggregated distributions of insects make trap catch very sensitive to trap placement (Cuperus, 1990). For relative population estimates, these factors can be incorporated into action threshold tables to assist stored-grain managers in interpreting trap catch and to make economically sound decisions (Higgins and Lippert, 1988; Cuperus et al., 1989). When samples are taken without monitoring these factors, there will be no way to remove the variability in trap catch, and estimates are likely to be inaccurate (Wright and Mills, 1984; Lippert and Hagstrum, 1987; Fargo et al., 1989;

Subramanyam and Harein, 1990). Variation in temperature and moisture within a grain mass results in some areas being more favorable for insects than others (Hagstrum, 1987). With adequate understanding of variables that affect trap catch, multiple regression analysis can be used to estimate absolute populations (Lippert and Hagstrum, 1987; Southwood, 1978).

Catches of insects within a probe trap can be correlated with their densities within the grain mass. A laboratory experiment showed that capture rates were strongly related to insect densities in wheat. A test for insect density ranging from one to three insects per kilogram, and temperatures between 20 and 40°C, showed that insect captures in WB II probe traps increased linearly with insect density in the grain but had a quadratic response to temperature (Toews and Phillips 2002). Advantages to insect sampling with traps include ease of use, increased sensitivity for adult insects (Barak and Harein, 1982, Lippert and Hagstrum, 1987), and ability to sample continuously over an extended period of time. New insect infestations are detected in traps earlier than in grain samples (Lippert and Hagstrum 1987, Vela-Coiffer et al. 1997).

The objectives of this study were to evaluate seasonal trends in stored-product insect captures inside a wheat storage bin using new type of screen trap for estimating insect activity in the headspace (i.e., moving in and out of the stored wheat) and in the grain mass using probe traps.  Temperature in the headspace and grain mass was also measured.

## Materials and Methods

This study was conducted on the site of the USDA Center for Grain and Animal Health Research (CGAHR) in Manhattan, Kansas. One 109,090 kg steel bin was used in study and it was filled with 108,000 kilos of winter wheat. The bin was 6.6 m diameter, 4.2 m to the eave height and 6.0 m to the peak height. The data collection period commenced in August 2009 and ended in June 2010. Insect monitoring was conducted using two methods; probe traps to measure insect activity in the grain mass and screen box traps to measure insect activity in the headspace. The grain was loaded on July 14th and aeration was set to 0.2 CFM/bushel. The wheat was cooled to 22°C in August, 15° C in September, and 7°C in late October, using a controller that activated the aeration fan whenever the temperature fell below the specified thresholds. Aeration airflow rate was approximately 0.2 $m^3$/m/metric ton). Overall, the fans ran for a total of 477 hours until they were turned off on October 26th. The purpose of the aeration was to cool the wheat as quickly as possible to reduce insect population growth. No other pest management tactics were applied to the bins.

## Probe Traps

Probe traps were used to record activity of insects within the grain mass. The probes were in the grain for an average of 13 days for each sampling period. Five 45 cm long WB-II probe® traps (Trécé Inc., Adair, OK) were placed in the grain 1 m from the edge of the inner bin wall, in the north, south, east and west sections of the bin, and in the center (21 m from the inner bin wall). The probe traps were emptied into vials and held for inset identification and counting.

## Screen traps

Flight off the grain surface and landing on the grain surface was measured using screen traps specifically developed for this project and designed to be placed on the grain surface. Each trap consisted of a 40 cm x 30 cm frame made from 4 cm thick wood boards screwed together. The top of the frame is covered with fiberglass screen with an opening size of approximately 1.9 mm that is held in place using a 40 cm x 30 cm metal frame with a width of 2.1 cm and thickness of 1 mm. The metal frame was held in place on the wood frame using eight bolts which passed through holes drilled in the wood frame and were secured using wing nuts. Both sides of the screen were coated with Tangle-Trap insect trap coating #95118 (The Tanglefoot Company, Grand Rapids, MI) which was applied with a brush at room temperature. The screens were on the grain mass for an average of 13 days.

The traps were placed on the surface of the grain adjacent to the locations where the probe traps were placed. When in position the screen was approximately 3 cm above the grain surface. Insects flying off of the grain surface presumably became stuck to the bottom of the screen and those landing on the grain surface would become stuck on the top of the screen. After a one week period, traps were removed and analyzed for insect counting and identification. After insect identification took place, before replacement of the traps in the bins took place, the traps were reconditioned by removal and disposal of the used screen, placement of new screen and coating it with Tangle-Trap.

Voucher specimens were removed from the screen using forceps and stored in 70% ethyl alcohol until they could be identified. Traps were placed at the center, north, south, east and west quadrants near the probe trap locations as described above.

## Insect Identification

All insects that were known stored product pests were collected and identified using keys in Gorham et al. (1987) to the family, genus, or species level. Insects caught in probe traps were placed in 70 % ethyl alcohol for storage. Insects caught on screen traps were counted and identified while on the screen and using a magnifying glass since insects could be damaged during removal from the sticky surface. Because insects could potentially crawl up the side of the screen trap and get stuck on the screen, any insects captured within 0.5 cm of the inner edge of the wood frame were not counted. Data analysis was conducted by recording both insect counts on screen traps and pitfall trap counts. Because of varying lengths of monitoring periods, insect counts were converted to the number captured per week. Specimens of all major species collected have been deposited as reference specimens in the Kansas State University Museum of Entomological and Prairie Arthropod Research voucher number 225.

### Temperature Measurement

Temperature was recorded at different depths below the grain surface (0.15 m, 0.30 m, 0.60 m and 0.91 m deep) and in the headspace (0.3 m above the grain surface) of the bin. Temperature was also measured using Hobo® data loggers (Onset Computer Corporation Bourne, MA). Temperature cables (MC6-HD, Onset Computer Corporation Bourne, MA) attached to a metal rod were inserted into the grain. A modified flange attached to the end of a standard grain probe was used to push the metal rod with attached cables and down to the desired depth. Temperature was monitored at three locations: in center of the grain (21 m from outer wall) and midway between the center of the grain and the outer wall (10.5 m from outer wall) along a north-south line. The data loggers were set to record temperature at two-hour intervals. The raw data was averaged among the three locations at each time point and then all recordings over a 24 hr period were averaged to obtain a daily average temperature. Outdoor ambient daily average temperature was obtained from a local weather station.

## Results

Four different species were caught in the screen traps and 10 species were caught in the probe traps, four species caught in both types of traps (Table 2.1). The most abundant species caught in the screen traps was the Indianmeal moth, while the most abundant species caught in the probe traps was the foreign grain beetle (Figure 2.1). The Indianmeal moth was much more prevalent in the headspace than in the grain mass, and tended to captured more on top of the screen trap than on the bottom suggested limited movement into and out of the grain mass (Fig. 2.1). The number and diversity of species varied over time in both the screen and probe traps and periods of activity in both locations tended to overlap, although headspace activity dropped off more quickly in the fall, except for one brief spike in activity, and picked up more quickly in the spring. Fungal feeding species were also quite prevalent in both the headspace and the grain mass. There were high captures of hairy fungus beetle and foreign grain beetle beginning from September and continuing until mid November.

There were no species that were exclusively caught in the screen traps without also being caught in the probe traps (Table 2.1). The predominate species found in the screen traps was the Indianmeal moth which was predominately recovered on the upper surface of the screen, although there was some capture on the lower surface. On both top and bottom surfaces of the screen traps, hairy fungus, foreign grain beetle and minute pirate bug were found indicating more active movement into and out of the grain mass (Figure 2.1). Species that were found in probe traps but not in screen traps include *Cryptolestes* spp., red flour beetle, sawtoothed grain beetle, Lathridiidae, Anthicidae and small eyed flour beetle.

The temperature-cooling pattern for the bin and over a period of several months is shown in Figure 2.1. Insect activity ceased altogether around mid December when average ambient temperatures reached a low of -20 °C, and resumed (Indianmeal moth) at the end of April when average ambient temperatures reached 20 °C. Headspace daily average temperature throughout the season was consistently higher than the average grain mass temperature and the average outside ambient temperature. Average headspace temperature was 1°C higher than depths of 0.15 m and 0.30 m within the grain mass. It was also 2°C higher than depths of 0.60 m and 0.91 m within the grain mass. The biggest difference in temperatures was between the headspace temperature and average outdoor ambient temperature, where the daily average headspace temperature was 9 °C warmer than outside throughout the season. Even though the headspace temperature was on average higher than the outdoor ambient temperature, the two followed a similar pattern of temperature fluctuation throughout the season whereas the grain mass temperature stayed more constant. The average starting temperature in the grain mass was 29.1°C at the beginning of August. The average ending temperature in the grain mass at the beginning of June 2010 19.5 °C. The average grain mass temperature throughout the season is 10.2 °C.

## Discussion

This project originally started out as a lesser grain borer monitoring project, but because of the absence of captures of this species, the project evolved into a broader study of the stored insect community of wheat and the trends in activity and grain temperature over time. Many of the species that were caught are not unique to stored wheat but can be found in many post-harvest locations (e.g., the fungus feeders like hairy fungus beetle, foreign grain beetle and Lathrididae). Stored grain insects can be classified as either internal or external feeders, with the internal feeders being the most damaging to whole grain. Few internal feeders were captured in this study, with external feeders accounted for the majority of insects captured throughout the one year monitoring trial. The results of this study support the idea that there is considerable insect activity in the headspace of stored grain and that insects are moving in and out of the grain mass.  This pattern of activity is strongly influenced by temperature. Insect activity appeared to be higher at the beginning of the season, and then dropped off during the fall and winter months. Headspace and grain temperature clearly increased from March through June and Figure 2.1

shows the beginning of insect activity in mid-May with Indianmeal moth captured on screen traps.

Indianmeal moth is a cosmopolitan pest of many different commodities including but not limited to ground and tree nuts, whole grains, dried fruits, chocolate, beans, seeds, flours and meals (Tzanakakis, 1959; Simmons and Nelson, 1975; Rees, 2004; Mohandass et. al., 2007). It is not very damaging to intact wheat kernels, and did not appear to be established within the grain mass. Because of its broad host range these moths may have been attracted to the grain odors emanating from the bin and aggregated in the headspace, even if they had a limited ability to establish infestations within the bin. The limited captures of this moth on the underside of the screen trap suggests that there was limited movement into and out of the grain. The hairy fungus beetle in contrast had high activity in the headspace, but similar captures on the upper and lower sides of the screen and recovery in the probe traps.

One important factor impacting insect movement within the grain mass and immigration is seasonal patterns in temperature, both in the grain mass and in the surrounding environment. A study performed by Flinn and Hagstrum (2011) showed that as temperature dropped in the grain mass, so did insect activity and catch numbers. Hagstrum and Subramanyam (2006) showed that the population growth rate of lesser grain borer in stored grain is primarily determined by grain temperature. In the autumn, the periphery of the grain bulk cools faster than the center and this allows insects to continue to reproduce in the center during the cold winter months in grain that is not cooled by aeration. Beetle populations may be higher in the center of the grain bulk because they are able to move from the cool periphery of the grain into the warm center (Hagstrum, 1987). Jian et al (2004) demonstrated that *C. ferrugineus* could detect temperature gradients in less than 1 hour, preferred warmer temperatures, and responded faster to steeper temperature gradients than to shallower ones. Athanassiou et al. (2011) showed that in a steel bin of stored wheat in central Greece, Indianmeal moth tended to be aggregated in the warmer central part of the bin and similar trends were also noted for rusty grain beetle.

In a study of the insect community in a stored maize facility (Nansen et al., 2004), seasonal fluctuations in insect species were common. The physical environment can play an important role in the establishment of insect population in grain masses. Small differences in temperature and grain moisture content have been shown to have a substantial impact on development time, mortality and fecundity of both stored product moths (Savov, 1973; Bell, 1975; Subramanyam and Hagstrum, 1993) and beetles (Longstaff, 1981; Jacob and Fleming, 1990; Throne, 1994) in North America. Another study by Dowdy (1994) showed that the rate that stored product insects migrate by flight into a grain storage facility is influenced by environmental conditions that mediate flight activity. Conditions such as temperature, humidity and light are all important. Another study showed that the mean numbers of rusty grain beetle and hairy fungus beetle caught entering bins was highest after 7 weeks of storage (September), foreign grain beetle after 9 weeks (late September or early October), and lesser grain borer after 11 weeks (October), and then the numbers of each species entering bins tended to decrease (Hagstrum 2000). Statistical correlation analysis using insect counts and average temperature will need to be performed to evaluate the impact of temperature in the current study.

Species caught on screen traps and probe traps were typical of those collected from stored wheat (Sedlacek, 1998). Hairy fungus beetle was a common species caught in the grain mass and on screen traps perhaps by crawling. Common fungal feeding insects associated with stored grain include the foreign grain beetle, hairy fungus beetle and rusty grain beetle (Lippert and Higgins, 1989; Throne et al., 2003). Foreign grain beetle and hairy fungus beetle were caught in large numbers within the grain mass. Red flour beetle was caught in the grain mass, but not in significant numbers.

The development of effective pest management programs requires an understanding of insect populations. Grain managers need the ability to anticipate when, where and to what extent infestations are likely to develop. We have a poor understanding of where insects come from in the environment and when and to what extent they migrate into stored grain (Dowdy and McGaughey, 1997). Results of this project show that there is considerable movement of insects into and out of grain, that insect activity outside the grain mass increases in the spring prior to the grain warming sufficiently to allow insect activity to be detected in the probe traps.  Grain warming in the spring and the impact on insect movement into and out of the grain is an area that needs further research.  Finally, this study provides temperature cooling and warming data that will be useful for modeling stored-product insect populations.

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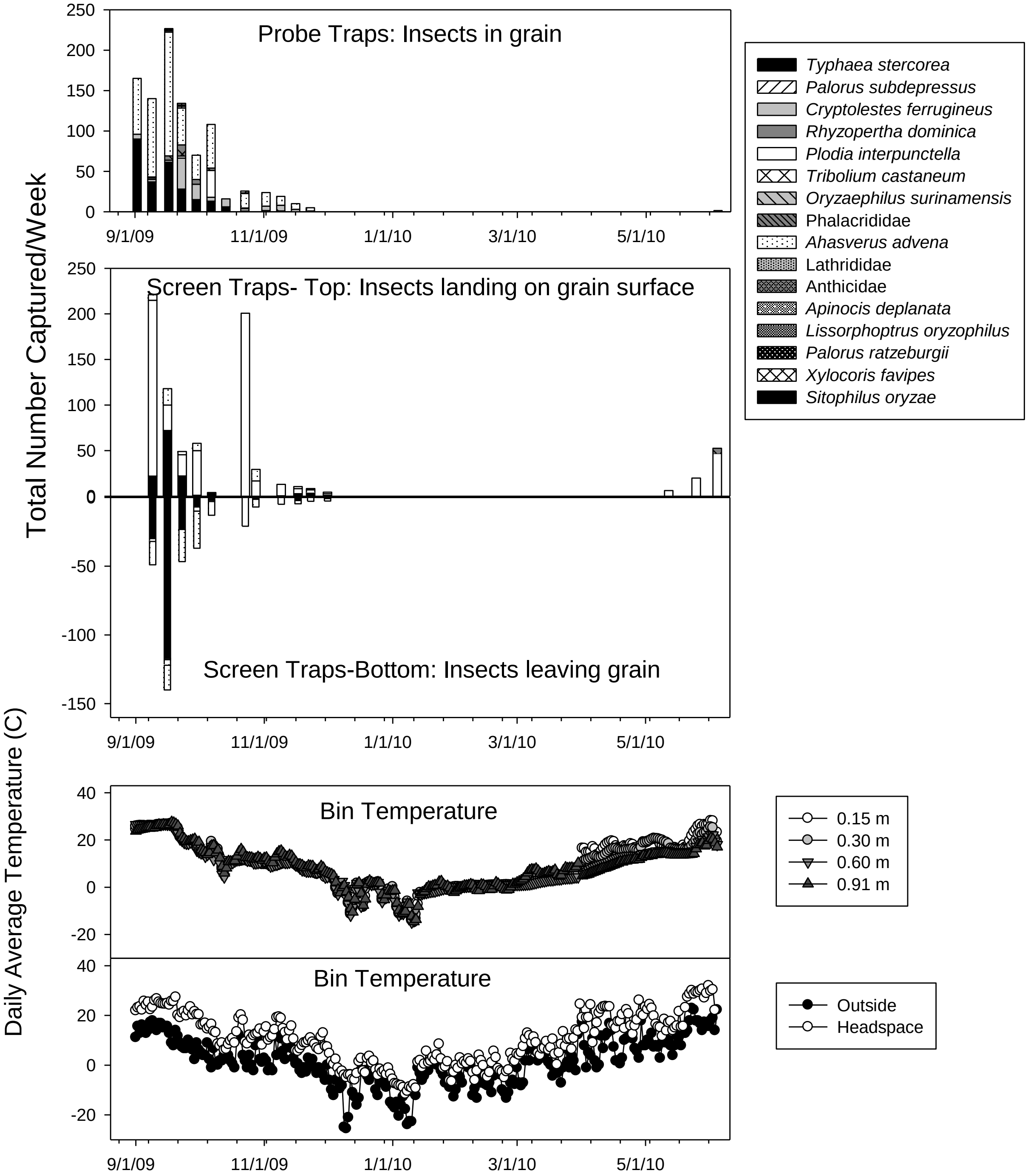
# Tables and Figures

**Table 2.1. Total number (percent of the total number captured) of stored-product insects recovered using probe traps in the grain mass and screen traps in the headspace of a wheat storage bin during 2009-2010 season in Manhattan, KS.**

| Species | Probe | Screen |
|---|---|---|
| *Typhaea stercorea* | 259 (27) | 127(14) |
| *Palorus subdepressus* | 0 (0) | 0 (0) |
| *Cryptolestes* spp. | 98 (10) | 0 (0) |
| *Rhyzopertha dominica* | 0 (0) | 0 (0) |
| *Plodia interpunctella* | 36 (4) | 721 (78) |
| *Tribolium castaneum* | 29 (3) | 0 (0) |
| *Oryzaephilus surinamensus* | 8 (.82) | 0 (0) |
| Phalacrididae | 0 (0) | 0 (0) |
| *Ahasverus advena* | 533 (54) | 58 (6) |
| Lathridiidae | 4 (.41) | 0 (0) |
| Anthicidae | 1 (.10) | 0 (0) |
| *Apinocis deplanata* | 0 (0) | 0 (0) |
| *Lissorhoptrus oryzophilus* | 0 (0) | 0 (0) |
| *Palorus ratzeburgii* | 2 (.20) | 0 (0) |
| *Xylocoris favipes* | 3 (.31) | 20 (2) |
| *Sitophilus oryzae* | 0 (0) | 0 (0) |

**Figure 2.1. Trends in capture of stored-product insect species over time in probe traps placed in grain mass and screen traps (upper and lower sides) placed on the grain surface in the headspace inside a wheat bin in Manhattan, KS.**



# Chapter 3 - Stored Product Insect Activity in Rice Bin Grain Mass and Headspace

# Abstract

The insect community of stored rice was assessed in six different bins of rough rice over two seasons in Beaumont, Texas. The majority of the stored product insect captures occurred when grain mass temperature was between 25 and 30° C.  The most abundant stored-product insect species captured in the grain using probes traps were *Typhaea stercorea* (L.) (Coleoptera: Mycetophagidae), *Sitotroga cerealella* (L.) (Coleoptera: Curculionidae), and *Ahasverus advena* (Coleoptera: Silvanidae) (Waltl) during the first year and *T. stercorea* and *Xylocoris favipes* (Reuter) (Hemiptera: Anthocoridae). The most abundant species caught in the headspace using screen traps was *S. cerealella* in the first year (80%) and *S. cerealella* and *T. stercorea* in the second year. Understanding the species diversity and seasonal patterns of activity can help with the targeting of pest management programs.

# Introduction

Postharvest losses of grain are often caused by insect infestation. Losses of stored grains by insect feeding amount to at least 5% of the annual production (White, 1953). This quantity may be substantially higher in developing countries (Saunders et al., 1980; Schulten, 1982) where proper postharvest loss prevention is often lacking (Sittisuang and Imura 1987). Reducing these losses have stimulated innovations in pest management including a focus on identifying the origin of the insects found in grain. Infestations can arise from residual populations in bins or machinery and immigration from adjacent bins, outside spillage or more distance sources.

The increasing costs of research, development and legal registration of conventional insecticides will limit the availability of new compounds for use in stored products. The process of registration in the United States may require 8-12 years and a capital cost of $40 to 80 million (Lethbridge, 1989; Woodhead et al., 1990). Currently pest management relies primarily on the use of fumigants, grain protectants, and temperature control using aeration. Alternative biological and microbial controls, mechanical controls, environmental manipulations and expert systems will increase in importance as management systems change in response to consumer demands, biological factors, economic conditions, and advances in integrated research (Arthur 1996).

Rice is a major commodity that is vulnerable to insect infestation. In the US, there are four major rice-producing regions: California, gulf coast, Arkansas/Missouri non-delta and the Mississippi river delta. Rough rice, because of its outer hull or husk, is the most resistant of the cereal grains to insect infestation; however, this varies greatly among the variety of rice and the insect species doing the attacking (Howe, 1965). Since 1911, about 140 varieties of rice have been released in the US with improved characteristics for agronomic production, field tolerance to insects and diseases, milling, baking quality and industrial cooking preferences (Moldenhauer et al., 2004). Rice varieties differ in their attractiveness to stored product insects and the level at which they may be infested (Cogburn, 1976). The hull thickness of rough rice varied among varieties but the tolerant varieties appeared to have thicker hulls than the susceptible varieties. There was no difference among rice types (long, medium or short grain) regarding tolerance or susceptibility to the lesser grain borer *Rhyzopertha dominica* (F) (Coleoptera: Bostrichidae) (Chanbang et al., 2007). Texture of husk influenced the development of both lesser grain borer and rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) (Prakash et al., 1986).

Insect infestation can significantly reduce the quality of rice, and thus its economic value (Cogburn, 1977). Weight loss affects the value placed on rough rice and the whole kernels that remain after completion of the milling process. Cracked or damaged hulls are more susceptible to insect exploitation. The number of lesser grain borer progeny produced increased as the proportion of kernels with cracked hulls increased (Kavallieratos et al., 2012). Insect infestation will reduce the dry weight of the lot and cause breakage of the kernels that would normally remain intact during processing (Cogburn, 1976a). There are four kinds of losses caused by stored product insects: quantitative (i.e., weight loss), qualitative (i.e., grain quality and wholeness), seed viability (i.e., ability of the seed to germinate), and damage to storage containers (e.g., damage of wood or polythene caused by lesser grain borer). This damage by primary feeders such as lesser grain borer and the rice weevil can make the rough rice more assessable to secondary feeders such as red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) (Hall and McFarlane, 1961). Insect feeding on grain degrades the nutrient and caloric values of food (Sinha and Campbell, 1975).

There is limited published information on the pest complex in rice and most of the information that is available is very dated. Hagstrum and Subramanyam (2009) list 167 species that can infest rice, ranking 3rd in the most species that is associated with a commodity just behind wheat and maize. Insects such as Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelichiidae), lesser grain borer and rice weevil are internal feeders which are able to exploit whole rough rice kernels, with development occurring inside the kernel. Grain borers occur regularly in rice storage (Sinha, 1973). Pests such as sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae); red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), hairy fungus beetle *Typhaea stercorea* (L.)(Coleoptera: Mycetophagidae), foreign grain beetle *Ahasverus advena* (Waltl) (Coleoptera: Silvanidae) are external feeders that require broken, damaged kernels or milled products for larval development. Factors such as relative humidity, grain moisture, temperature, light, types of storage containers, storage practices, storage periods and fungi can influence storage losses due to insects (Sinha, 1973). Fungi also cause physical and chemical deterioration of stored grains (Christensen, 1974). When storage insects feed and develop on and inside of the grain, biochemical degradation is the result, for example, in stored rice, total number of amino acids is found to be reduced by insect infestation in raw and par boiled rice grains (Sudhakar and Pandey, 1983). Insects in stored rice are also found to enhance moisture content and allow molds to grow (Kauraw and Prakish, 1980).

Temperature management is important for reducing pest development. Temperature affects the activity of enzymes, the properties of cell membrane as well as other physiological activities, and consequently the development and behavior of organisms (Wang et al. 2004). A study by Hagstrum and Subramanyam (2006) showed that population growth rate is primarily determined by grain temperature. Bulk stored grain is an artificial ecosystem where living organisms and their nonliving environment interact. This ecosystem is influenced by outside conditions such as seasonal weather variation. The external temperature changes cause temperature gradients with the grain mass, which may influence distribution of stored grain pests within the bulk (Jian et al., 2004). Hagstrum and Flinn (2011) showed that lesser grain borer preferred the moderate temperature region in a gradient from 42 to 20° C, and avoided the highest temperature region. Grain temperature impacts the capture of insects in traps placed in the grain. Fargo et al. (1989) has shown that stored grain insects captured in drop traps placed in wheat was affected by insect species, grain temperature, and trapping duration. Higher grain temperatures resulted in significantly more insects trapped when all species were combined. Temperature also influences insect immigration into bins. Hagstrum (2000) in a study of insect immigration into wheat bins that could be relevant to rice, showed that the mean numbers of lesser grain borer, *Cryptolestes* spp. and hairy fungus beetle caught in ventilation traps were highest in the early fall and dropped as temperatures decreased. Grain temperature can be managed through effective aeration. Arthur et al. (2011) showed that the predicted population levels in aerated rice represented at least a 98% reduction of lesser grain borer and rice weevil compared with unaerated rice.

The major objectives of this study were to evaluate seasonal trends of stored-product insect diversity and abundance in stored rice and to measure seasonal trends in grain and grain bin headspace temperature.

## Materials and Methods

This study was conducted at the Texas A&M AgriLIFE Research Center located in Beaumont, TX. Six corrugated 20,411 kg steel bins (3.6 m diameter, 4.8 m height to eave, and

1.06 m from eve to top of bin), spaced approximately 0.66 m apart, were used. The Texas Rice Improvement Association dictated the variety and amount of rice stored and the times it was added and removed from the bins. These bins were used for storing different rice varieties prior to planting, which resulted in variation in rice varieties and time of loading and unloading among the bins and years. Monitoring of insects and temperature was conducted over two seasons: August 2009 to February 2010 (season 1) and September 2010 to February 2011 (season 2). Information on rice bin variety and amount of rice, fill and empty date, and experimental treatments are provided in Table 3.1 for 2009-2010 and Table 3.2 for 2010-2011.

## Rice Management Tactics

The rice in the six bins was exposed to different pest management tactics, although these different tactics are specifically evaluated as part of this study. In season 1, there were two control bins that were not scheduled to receive any treatments, two bins receiving aeration alone, and two bins receiving aeration and methoprene (Table 3.1). Aeration involved manual turning on and off of the fans, with aeration applied between October 23, 2009 and December 21, 2009. In the end, aeration was not optimally applied and did not result in observable changes in grain temperature. The aeration was performed on October 23rd (11:15 am to 1:15 pm), October 24th (11:15 am to 1:15 pm), November 2nd ( 9:15 am and ended at 11:20 am), November 3rd (8:15 am to 10:55 am), November 18th (9 am to 11:20 am), December 2nd (9:00 am to 3:00 pm) and December 21st (9:00 am to 12:38 pm). Bins receiving the grain protectant methoprene treatment were treated with a target rate of 2.5 ppm Diacon II (Central Life Sciences, Schaumburg, IL). The two control bins were scheduled not to be treated, but one of the bins (#6) became so heavily infested that it fumigation was required. Two separate treatments were performed with Profume on 10/15/2009 and Phosphine on 11/6/2009. In season 2, the same six bins were used but with different rice varieties and load and unload dates (Table 3.2). Three of the bins were treated with the same target rate of Diacon II as in season 1.

## Insect Monitoring Methods

Insect monitoring was conducted using two methods.  Probe traps were used to measure insect activity in the grain mass and screen box traps were used to measure insect activity in the headspace.

Insect activity in the grain mass was measured using three 0.45 m long Storgard WB II polyethylene grain probe traps (Trécé, Adair, OK). Probe traps have the upper portion perforated with 2.79 mm diameter holes, small enough for insects to enter but not grain kernels, and the lower portion consisting of a collection tube made of smooth plastic with no perforations. Three probe traps per bin were inserted into the grain at a depth of 0.45 m below the surface at the center of the bin, and at midpoints between the center and the bin wall in a south-north direction. The center probe was placed at 1.79 m from the inner bin walls and the north and south probes were placed 0.89 m from the center probe and bin walls. The probes were removed from the grain weekly and the insects in the collection tube removed. The collected insects were transferred to vials and shipped to USDA ARS CGAHR laboratory in Manhattan, KS for identification and enumeration.  Sometimes weather conditions impacted the ability to enter bins so the trapping intervals varied.

Insect flight from the grain surface and landing on the grain surface was measured using screen traps specifically developed for this project and designed to be placed on the grain surface, referred to hereafter as “screen traps”. Each trap consisted of a 40 cm x 30 cm frame made from 4 cm thick wood boards screwed together. The top of the frame was covered with fiberglass screen with an opening size of approximately 1.9 mm square that was held in place using a 40 cm x 30 cm metal frame with a width of 2.1 cm and thickness of 1 mm. The metal frame was held in place using eight bolts that passed through holes drilled in the wood frame and were secured using wing nuts. Both sides of the screen were coated with Tangle-Trap insect trap coating (#95118, The Tanglefoot Company, Grand Rapids, MI) that was applied to the screening with a brush at room temperature. When in position on the grain the screen of the screen trap was approximately 3 cm above the grain surface. Insects stuck to the bottom of the screen represent individuals flying off of the grain surface and those stuck on the top of the screen represent individuals flying in the headspace and landing on the grain surface. Because insects could crawl up the side of the screen box trap and get stuck along the edge of the screen, to only recorded flight activity any insects captured within 0.5 cm of the inner edge of the wood frame were not counted.

The screen traps were placed on the surface of the grain in the six bins, three per bin adjacent to the locations of the probe traps. Traps were placed at the North, South, and Center quadrants. The center screen was placed at 1.79 m from the inner bin walls at the same location to the center probe. The north and south screens were placed in the same location to the probes at 89 cm from the center probe and bin walls.

Screens were left on the grain for a week and were then removed and shipped to the USDA ARS CGAHR laboratory for identification and counting. Only voucher specimens were removed from the screen using forceps and stored in 70% ethyl alcohol until they could be identified. Insects caught on screen traps were counted and identified while on the screen and using a magnifying glass since insects could be damaged during removal from the sticky surface. Because of the shipping and processing time the traps were not in place continuously as was the case with the probe traps. Traps were reconditioned by replacing the old screen with a new piece of screen and coating it with Tangle Trap as described above.

## Insect Identification and Enumeration

All stored product insects collected were identified using keys in Gorham et al. (1987) to the family, genus, or species level. Insects caught in probe traps were transferred to 70% ethyl alcohol for storage before counting and identification. Two non-stored product weevil species were observed in sufficient numbers and over a long enough period of time that they were identified and counted as well. One species was identified by associate curator Edward Riley, Texas A&M University, College Station and the other was identified by Holly Davis at Kansas State University.

Because of varying lengths of monitoring periods, insect counts were divided by the number of days the traps were in place and then multiplied by 7 days to convert to number captured per week. Specimens of all major species collected have been deposited as reference specimens in the Kansas State University Museum of Entomological and Prairie Arthropod Research (accession number 225).

## Temperature Measurement

During the 2009-2010 and 2010-2011 trial, temperature was monitored throughout the season in the north, south and center quadrants. Temperature was recorded at depths of 0.15 m, 0.30 m, 0.60 m and 0.91 m below the grain mass, and also measure in the headspace at a height of 0.30 m by five Hobo® data loggers (H-8 series, 4 channel, Onset Computer Corporation Bourne, MA). Temperature cables were MC6-HD cables, Hobo® data loggers (Onset Computer Corporation Bourne, MA) and were attached to each logger and mounted to a metal rod that could be inserted into the grain.  A modified flange attached to the end of a standard grain probe was used to push the cable and the temperature sensor down to the desired depth. The modified cylindrical metal flange with slots on either side was attached to the end of a standard grain probe. The cable fit in the slots of the flange and the probe was used to push the cable and the temperature sensor down to the desired depth. The HOBO data loggers were placed at the north and south coordinates 89 m from the center probe and inner bin walls. The center probe was located at 1.79 m from the inner bin walls.

The data loggers were set to record temperature at two-hour intervals. The raw data was exported and the daily average of the different coordinates for each depth was calculated using SAS® (SAS Institute, 2002 Cary, NC). Outdoor ambient temperature was monitored using an onsite weather station located adjacent to the bins and daily average temperature calculated from this data. There were HOBO logger failures resulting in erroneous data which were far out of the bounds of other temperature readings in the bins. A protocol was developed to handle erroneous data such that any temperature reading within 2 hours of another other that was more than 20 degrees different it was deleted.

## Results

The most damaging insect species recovered in large numbers was the Angoumois grain moth, while the other most abundant species tended to be fungus feeders. There were noticeable differences in insect activity between season one and two in the number of insect taxonomic groups captured in the grain mass. In season one there were sixteen different recorded species in the grain mass (Table 3.3), but only five taxonomic groups in season two (Table 3.5). Season one had high captures of hairy fungus beetle and Angoumois grain moth which, were also captured in the second season, albeit in lower numbers.

In season one 2009-2010, hairy fungus beetle was the predominate species captures in the grain using probe traps and Angoumois grain moth were the dominant species caught in in the headspace using the screen traps.  However, it should be noted that Angoumois grain moth was also caught in significant numbers in the probe traps. There was considerable variation among bins and between years in the captures of Angoumois grain moth. A graphical representation of the numbers captured in probe and screen traps over the course of the study is shown in Figures 3.1-3.6. Large populations of hairy fungus beetle were consistent and present in every bin except bins 4 and 6 in season one (Table 3.3). Anthicidae was only found in bin 1 and 4 and foreign grain beetle was found in every bin except bin 5 and 6. Contrasting this, in season two, hairy fungus beetle was found in all bins and minute pirate bug was found in all bins except 6 whereas in season one it only showed up in bin 5 (Table 3.5).

Two species of weevil were abundant in probe traps during season 1 that are not classified as stored product insects. One was identified as the rootstock weevil and was caught in bins 3-6 and the other was the rice water weevil, which was caught in bins 1, 3, 4 and 5 (Table 3.3).  These species were recovered in probe trap samples in the samples of the first monitoring period after harvest and might have been collected at rice harvest and moved into the bins, although they might also enter bins searching for overwintering sites.

The seasonal trends for insect captures in the probe traps followed a trend of starting off high and then gradually declining after November in both seasons. However insect activity did not reach zero during the winter, although the full activity over the winter could not be measured since the bins were emptied before spring. What varied the most was when certain species would show up, this was highly variable from bin to bin in season 1. In season 2 there was generally a lot of insect activity right after bin loading and then this activity declined as the months progressed toward winter (Figure 3.7-3.12). Table 3.5 shows that hairy fungus beetle was captured in all bins, as was Angoumois grain moth. Minute pirate bug was caught in bins 1-5, but in very high numbers (53 percent of seasonal captures) in bin 3 and that foreign grain beetle was captured in bins 1-4 and 6 (Table 3.5).

The predominate species found in the screen traps in both season 1 and 2 was Angoumois grain moth which was found on both the upper and lower surface, as well as in the probe traps, indicating movement into and out of the grain mass. Hairy fungus beetle was also active in the headspace and captured on both sides of the trap and in probe traps, showing it was also actively moving into and out of the grain (Figures 3.1-3.12).

There were differences among the bins in species abundance in the headspace. Some taxonomic groups were unique to certain bins in season one; e.g., anthicids were limited to bins 1 and 4, foreign grain beetle was limited to bins 1-4, and rootstock weevil was only in bin 2 (Table 3.4). Hairy fungus beetle and Angoumois grain moth are distributed unevenly across all bins. In season one, bins 5 and 6 have the highest concentration of moths while the middle bins, 3 and 4 have the lowest. In season two, bins 1 and 6 had higher counts of moths and bins 2-5 had the lowest.

Insect activity was highest at the beginning of the season during when grain temperature was warmest in the months of September and October and steadily declined toward the onset of cooler temperatures (Fig. 3.1-3.6). The trends in species capture over time also varied from bin to bin especially in season one. Besides Angoumois grain moth which was predominant, incidentals such as foreign grain beetle, hairy fungus beetle and anthicids tended to be caught during the first two monitoring periods and then not be seen again throughout the rest of the monitoring period (Figures 3.1-3.6).

In both season one and two, there were no species that were exclusively caught in the screen traps without also being caught in the probe traps (Tables 3.3-3.6). Species that were found in probe traps but not in screen traps in season one include depressed flour beetle, *Cryptolestes* spp., lesser grain borer, red flour beetle, sawtoothed grain beetle, phalacrididae, lathridiidae, rice water weevil, small-eyed flour beetle and rice weevil. In season two, foreign grain beetle, anthicidae and minute pirate bug were found in the grain mass but not the screen traps. Insects tended to be active for a longer period of time in the headspace than in the grain mass after grain was loaded into bins in the fall.

Temperature in the grain mass varied with depth and was more constant than in the headspace which tended to have greater daily and seasonal fluctuates. Bins 1 and 2 had temperatures at all depths that seemed to be close together and more consistent. Bins 1 through 6 had the first three depths which followed a similar cooling pattern while the depth of 0.91 m seemed to fluctuate the most by either falling below the pattern or rising above it in isolated brief increases. Headspace temperature was seemed to be closely related with outside ambient temperature.

The temperature data for season one is shown starting in figure 3.1 for bin 1 through figure 3.6 for bin 6. The average rate of cooling for all bins over season one was 11°C and their average starting and ending temperatures were 25.1°C and 13.4°C. During season two, the temperature patterns are shown starting in figure 3.7 for bin 1 through figure 3.12 for bin 6. In season two the average rate of cooling for all bins was 8.3°C and their average starting and ending temperatures were 26.2°C and 17.9°C, respectively. Season two was slightly warmer than season one; starting out 1.1°C warmer and ending 4.5°C warmer.

# Discussion

This project originally started out as a lesser grain borer monitoring project but because of the low captures, the project evolved into a study of the stored-product insect community found in rough rice bins. Many of the species that were caught are not unique only to rice, but can be found across the board in a stored grain environments; especially the fungus feeders like hairy fungus beetle, foreign grain beetle and lathrididae. Counts of external feeders in the grain mass in season one and two outnumbered internal feeders with a ratio of 10/5 for season one and 3/1 for season two. Counts of external feeders in the headspace in season one outnumbered internal feeders with a ratio of 3/2 and a ratio of 1/1 in season two.

The results of this study support the idea that insect captures in traps in grain is related to the grain temperature. Given the activity in the headspace, our findings suggest that insects are still active in the headspace and potentially the surface layers of the grain. There were differences in trends between season one and season two that are interesting. The temperature in season two was slightly warmer over all sampling periods than season one, however insect abundance and diversity was less in season two. There were larger numbers of the predacious minute pirate bug in season two, which might explain this decline since it is a predator of many stored-product pest species.

In the future, it will be necessary to perform correlation analysis using the insect counts and the average temperature. The reason for the decreased insect captures in traps with lower grain temperatures is likely due to the simple fact that insects are poikilotherms and their movement decreases with temperature. In a study by Saska et al. (2013) temperature was the most important of all studied weather variables. Multiple regression analyses of 19 data sets showed that temperature is the key climatic variable affecting total catch. Another study by

Honek (1997) showed that the number captured increased in the average of 6.3 percentage points per 1°C increase of average temperature.

Insects that feed on fungi are common in grain and grain products that are improperly stored at high moisture level (Sinha and Wattars, 1985). The most common fungal feeding insects associated with stored grain include the foreign grain beetle, hairy fungus beetle and rusty grain beetle (Throne et al., 2003). The high presence of hairy fungus beetle in the stored rice shown mass, could be an indicator of moisture problems in the grain. However, although the moisture content in the grain was not monitored during this particular experiment there were no indications of grain spoilage during the relatively short period of time the rice was stored. Activity of hairy fungus beetle in the grain and headspace, probably indicates movement of individuals into and out of the bins, with the origin being degraded rice spillage in the outside environment. However, this needs further evaluation.

Insect species not commonly associated with stored rice were found in season one but not season two. The rootstock weevil, is a common weevil found in Texas (Goode and Randolph, 1961). This weevil may be an occasional contaminant of stored grain, particularly sorghum. Though it is not known to feed on harvested grain, it can (because of its similar size) be confused with grain damaging species (Brooks et al., 2002). The larvae are often stem borers (Davis, 2008). The rice water weevil is one of the most destructive insect pests of rice in the U.S. and some rice growing regions of eastern Asia (Way, 1990; Chen et al., 2005; Saito et al., 2005). It is not considered a stored grain insect pest, but a pest in the field preharvest because of its ability to root prune individual rice plants. Presence in the stored rice might be because they were using it as an overwintering site. The rice is warmer than the outdoor environment and the temperature is more stable. When the rice was harvested, there may have been a high infestation of both weevils in the field and they were subsequently transported via combine to the bin or moved on their own from the rice fields into the bins. The rootstock weevil can use weed grasses as alternative hosts along the gulf coast, particularly in the winter (White and Carlton, 2012). Rice water weevil utilizes several different types of grasses that may have been present in the field, with some species such as broadleaf signalgrass, *Brachiaria platyphylla,* barnyardgrass, *Echinochloa crus-galli,* yellow nutsedge, *Cyperus esculentus,* and fall panicgrass, *Panicum dichotomiflorum* were more preferred for oviposition than rice (Tindall and Stout, 2003). These weeds may have been present in the fields around the rice storage and the insects moved from there into the rice bins.

In season one and two, the predacious minute pirate bug was present in the rice bins. *Xylocoris* (Doufour) is a large anthocrine flower bug genus, comprising about 50 species in the world, principally in the Holaretic Region (Chu, 1969; Pericart, 1996). These bugs usually prey on various small arthropods and some have been reported to be effective natural enemies against pests in stored-food facilities and grain mills (Lattin 2000). Minute pirate bug is a well-known predator of stored product insect pests (Yamada, 2006).

The screen traps had excess captures of angoumois grain moth, which were particularly heavy in season one. Angoumois grain moth is a serious pest of cereal grains. It is cosmopolitan in distribution. The economic losses caused by this insect have been reported to range from 13.1 to 24.0% (Gerbierge and Goldhein, 1957; Moore et al., 1966).

While varietal resistance wasn’t part of this study, it is worth mentioning the varieties because previous studies, Chanbang et al. (2008) described how hull characteristics influence the susceptibility of different varieties of rough rice to lesser grain borer. In another study, Throne et al. (2000) discussed varietal resistance and how it can be used to improve pest management plans for stored commodities. Cogburn (1976b) showed that there was a correlation between rice variety and resistance to certain stored product insects. The varieties of rice stored in the different bins may have contributed to variation in insect abundance and diversity among the bins.

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# Tables and Figures

**Table 3.1. Season 1 (2009-2010) rice bins: variety and amount of rice stored, fill and empty dates, and treatments applied.**

| Bin | Amount of Rice (kg) | Variety | Fill Date | Empty Date | Treatments |
|---|---|---|---|---|---|
| 1 | 17,852 | Sabine | 9/9/2009 | 2/5/2010 | Aeration |
| 2 | 13,581 | Rhonda | 9/16/2009 | 2/5/2010 | Aeration, Methoprene |
| 3 | 10,052 | Carolina Gold | 10/6/2009 | 12/16/2009 | Control |
| 4 | 10,225 | Neches HR | 10/14/2009 | 2/8/2010 | Aeration |
| 5 | 18,136 | Neptune | 9/19/2009 | 2/8/2010 | Aeration, Methoprene |
| 6 | 8,146 | Diecibelle | 8/11/2009 | 1/20/2010 | Control, but insect infestation lead to two fumigations (Profume, Phosphine) |

**Table 3.2. Season 1 (2010-2011) rice bins: variety and amount of rice stored, fill and empty dates, and treatments applied.**

| Bin | Amount of Rice (kg) | Variety | Fill Date | Empty Date | Treatments |
|---|---|---|---|---|---|
| 1 | 30,860 | Sabine | 9/3/2010 | 1/21/2011 | Methoprene |
| 2 | 32,280 | Sabine | 9/3/2010 | 1/28/2011 | None |
| 3 | 33,488 | Rondo | 9/9/2010 | 2/10/2011 | Methoprene |
| 4 | 24,500 | Sierra | 10/5/2010 | 1/4/2011 | None |
| 5 | 30,900 | Presidio | 9/5/2010 | 1/11/11 | Methoprene |
| 6 | 36,097 | Rondo | 9/6/2010 | 2/10/11 | None |

**Table 3.3. Total number (percent of the total number captured in a bin) of insects recovered using probe traps placed in six rice storage bins in Beaumont TX in season 1 (2009-2010)**

| Species | Bin 1 | Bin 2 | Bin 3 | Bin 4 | Bin 5 | Bin 6 | Total |
|---|---|---|---|---|---|---|---|
| *Typhaea stercorea* | 1003 (82) | 1829 (95) | 1040 (75) | 289 (32) | 802 (93) | 167 (12) | 5130 |
| *Palorus subdepressus* | 4 (.3) | 18 (.9) | 1 (.07) | 1 (.1) | 0 (0) | 0 (0) | 24 |
| *Cryptolestes* spp. | 0 (0) | 3 (.2) | 6 (.4) | 0 (0) | 0 (0) | 0 (0) | 9 |
| *Rhyzopertha dominica* | 0 (0) | 0 (0) | 2 (.1) | 0 (0) | 0 (0) | 21 (2) | 23 |
| *Sitotroga cerealella* | 5 (.4) | 3 (.1) | 5 (.4) | 1 (.1) | 24 (3) | 1059 (76) | 1097 |
| *Tribolium castaneum* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (.1) | 130 (9) | 131 |
| *Oryzaephilus surinamensus* | 12 (.10) | 6 (.3) | 0 (0) | 6 (.7) | 6 (.7) | 3 (.2) | 33 |
| Phalacrididae | 0 (0) | 0 (0) | 7 (.5) | 49 (5) | 2 (.2) | 1 (.07) | 58 |
| *Ahasverus advena* | 69 (6) | 18 (.9) | 209 (15) | 117 (13) | 4 (.5) | 3 (.2) | 420 |
| Lathridiidae | 102 (8) | 10 (.5) | 43 (3) | 20 (2) | 0 (0) | 1 (.07) | 176 |
| Anthicidae | 14 (1) | 5 (.2) | 33 (2) | 49 (5) | 1 (.1) | 2 (.1) | 104 |
| *Apinocis deplanata* | 0 (0) | 0 (0) | 5 (.3) | 25 (3) | 1 (.1) | 2 (.1) | 33 |
| *Lissorhoptrus oryzophilus* | 3 (.2) | 0 (0) | 19 (1) | 313 (35) | 20 (2) | 0 (0) | 355 |
| *Palorus ratzeburgii* | 6 (.5) | 27 (1) | 10 (.7) | 2 (.2) | 0 (0) | 0 (0) | 45 |
| *Xylocoris favipes* | 0 (0) | 7 (.3) | 12 (.9) | 3 (.3) | 1 (.1) | 0 (0) | 23 |
| *Sitophilus oryzae* | 0 (0) | 1 (.05) | 0 (0) | 18 (2) | 1 (.1) | 1 (.07) | 21 |

**Table 3.4 Total number (percent of the total number captured in a bin) of insects recovered using screen traps placed in six rice storage bins in Beaumont TX in season 1 (2009-2010)**

| Species | Bin 1 | Bin 2 | Bin 3 | Bin 4 | Bin 5 | Bin 6 | Total |
|---|---|---|---|---|---|---|---|
| *Typhaea stercorea* | 13 (8) | 18 (13) | 12 (23) | 0 (0) | 19 (9) | 0 (0) | 43 |
| *Cryptolestes* spp. | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Rhyzopertha dominica* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Plodia interpunctella* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Sitotroga cerealella* | 138 (84) | 110 (83) | 39 (74) | 19 (46) | 187 (90) | 2153 (100) | 2646 |
| *Tribolium castaneum* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0(0) | 0 (0) | 0 |
| *Oryzaephilus surinamensus* | 0 (0) | 0(0) | 0 (0) | 0(0) | 0 (0) | 0 (0) | 0 |
| Phalacrididae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Ahasverus advena* | 10 (6) | 3 (2) | 4 (2) | 13 (32) | 0 (0) | 0 (0) | 30 |
| Lathridiidae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Anthicidae | 3 (2) | 0(0) | 0 (0) | 9 (22) | 0 (0) | 0 (0) | 12 |
| *Apinocis deplanata* | 0 (0) | 1 (.7) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 |
| *Lissorhoptrus oryzophilus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Palorus ratzeburgii* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Xylocoris favipes* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (.48) | 0 (0) | 1 |
| *Sitophilus oryzae* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |

**Table 3.5. Total number (percent of the total number captured in a bin) of insects recovered using probe traps placed in six rice storage bins in Beaumont TX in season 2 (2010-2011)**

| Species | Bin 1 | Bin 2 | Bin 3 | Bin 4 | Bin 5 | Bin 6 | Total |
|---|---|---|---|---|---|---|---|
| *Typhaea stercorea* | 1137 (96) | 1858 (98) | 866 (44) | 289 (95) | 344 (97) | 2613 (99) | 7107 |
| *Palorus subdepressus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Cryptolestes* spp. | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Rhyzopertha dominica* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Sitotroga cerealella* | 37 (3) | 4 (.21) | 3 (.15) | 3 (.98) | 5 (1) | 1(0.04) | 53 |
| *Tribolium castaneum* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Oryzaephilus surinamensus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Phalacrididae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Ahasverus advena* | 4 (.3) | 6 (.32) | 48 (2) | 8 (3) | 0 (0) | 22 (0.83) | 88 |
| Lathridiidae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Anthicidae | 4 (.3) | 0 (0) | 14(.71) | 1 (.33) | 0 (0) | 3 (0.11) | 22 |
| *Apinocis deplanata* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Lissorhoptrus oryzophilus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Palorus ratzeburgii* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Xylocoris favipes* | 3 (.25) | 34 (2) | 1052(53) | 4 (1) | 6 (2) | 0 (0) | 1099 |
| *Sitophilus oryzae* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |

**Table 3.6. Total number (percent of the total number captured in a bin) of insects recovered using screen traps placed in six rice storage bins in Beaumont TX in season 2 (2010-2011)**

| Species | Bin 1 | Bin 2 | Bin 3 | Bin 4 | Bin 5 | Bin 6 | Total |
|---|---|---|---|---|---|---|---|
| *Typhaea stercorea* | 0 (0) | 23 (72) | 5 (19) | 2 (40) | 3 (16) | 35 (58) | 68 |
| *Palorus subdepressus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Cryptolestes* spp. | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Rhyzopertha dominica* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Sitotroga cerealella* | 29 (100) | 9 (28) | 21 (81) | 3 (60) | 16 (84) | 25(42) | 103 |
| *Tribolium castaneum* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Oryzaephilus surinamensus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Phalacrididae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Ahasverus advena* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Lathridiidae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| Anthicidae | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Apinocis deplanata* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Lissorhoptrus oryzophilus* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Palorus ratzeburgii* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Xylocoris favipes* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |
| *Sitophilus oryzae* | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 |

**Figure 3.1. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one; bin 1; Loaded 9/9/09; Unloaded 1/26/10.**

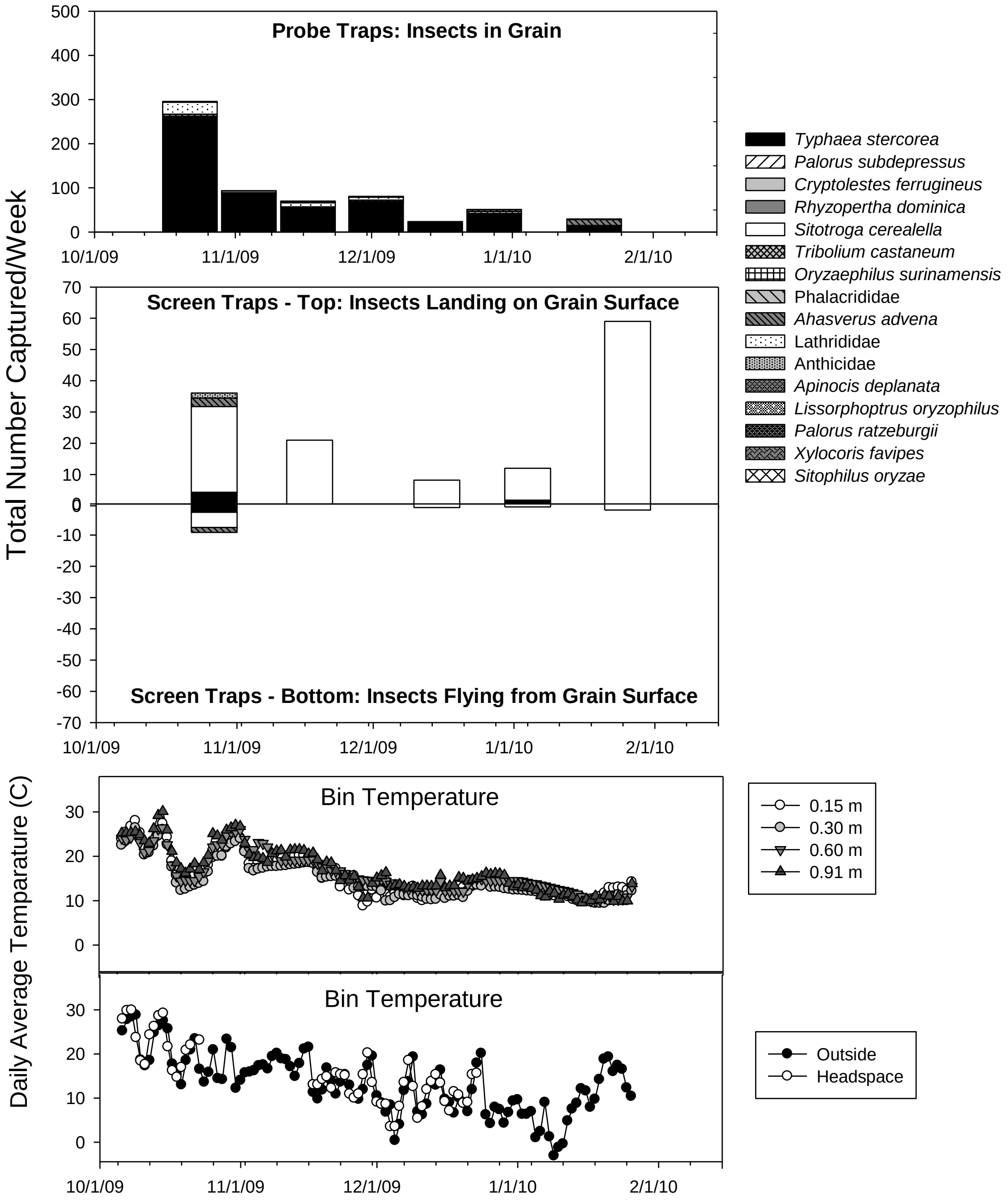

**Figure 3.2. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one, bin 2; loaded 9/16/09; unloaded 2/5/10.**

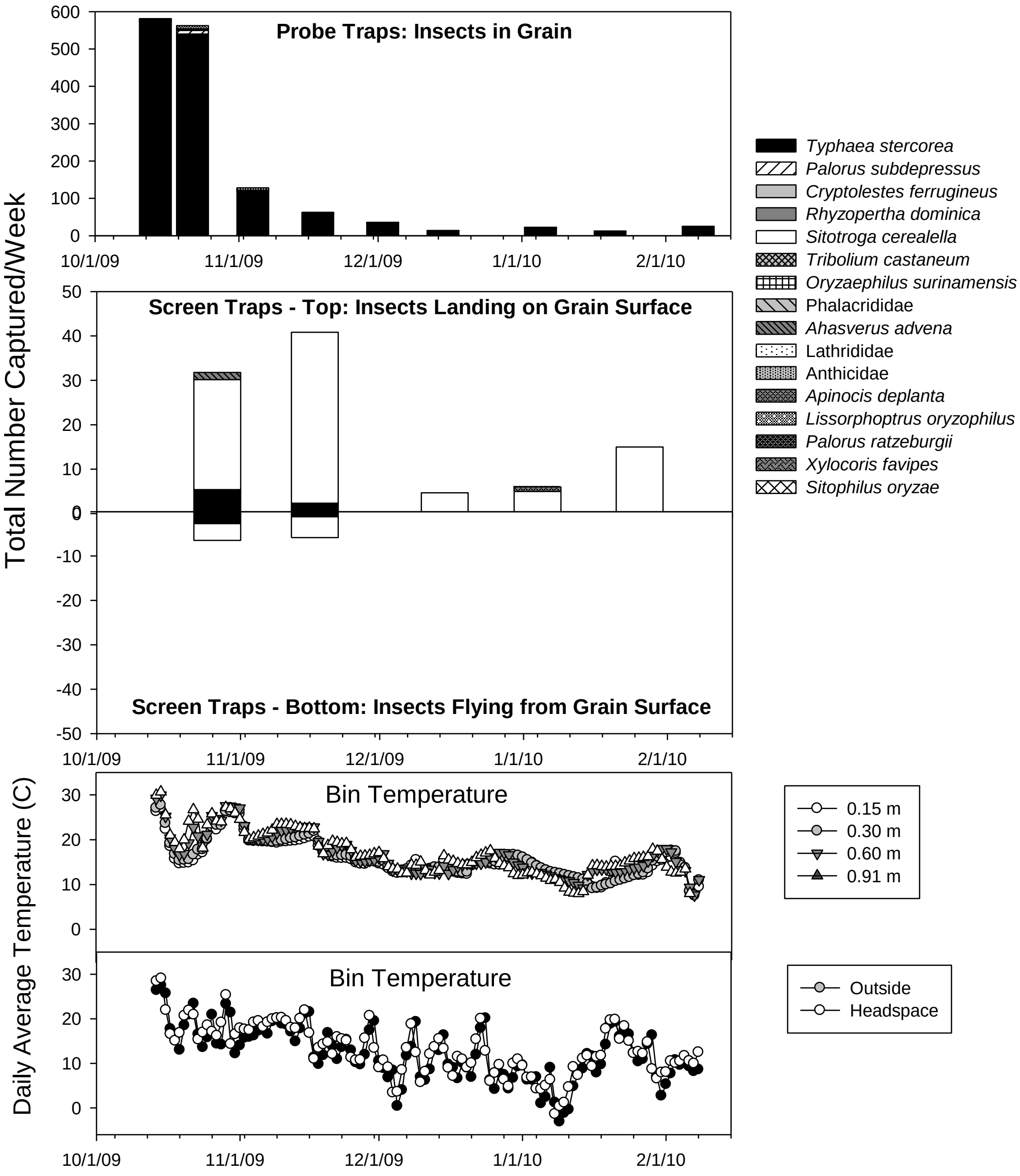

**Figure 3.3. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one; bin 3; loaded 10/6/09; unloaded 12/16/09.**

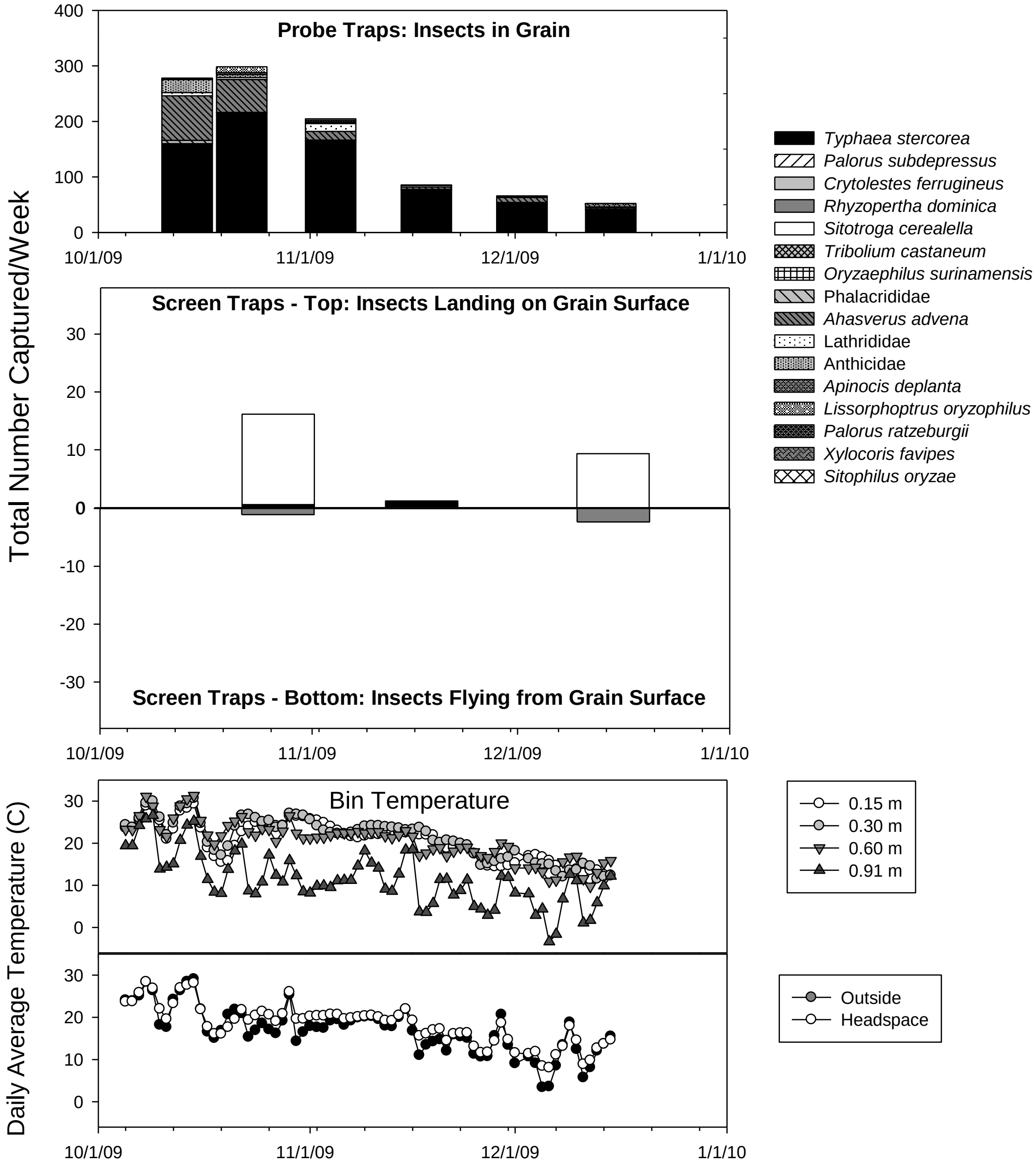

**Figure 3.4. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one; bin 4; loaded 10/14/09; unloaded 2/8/10.**

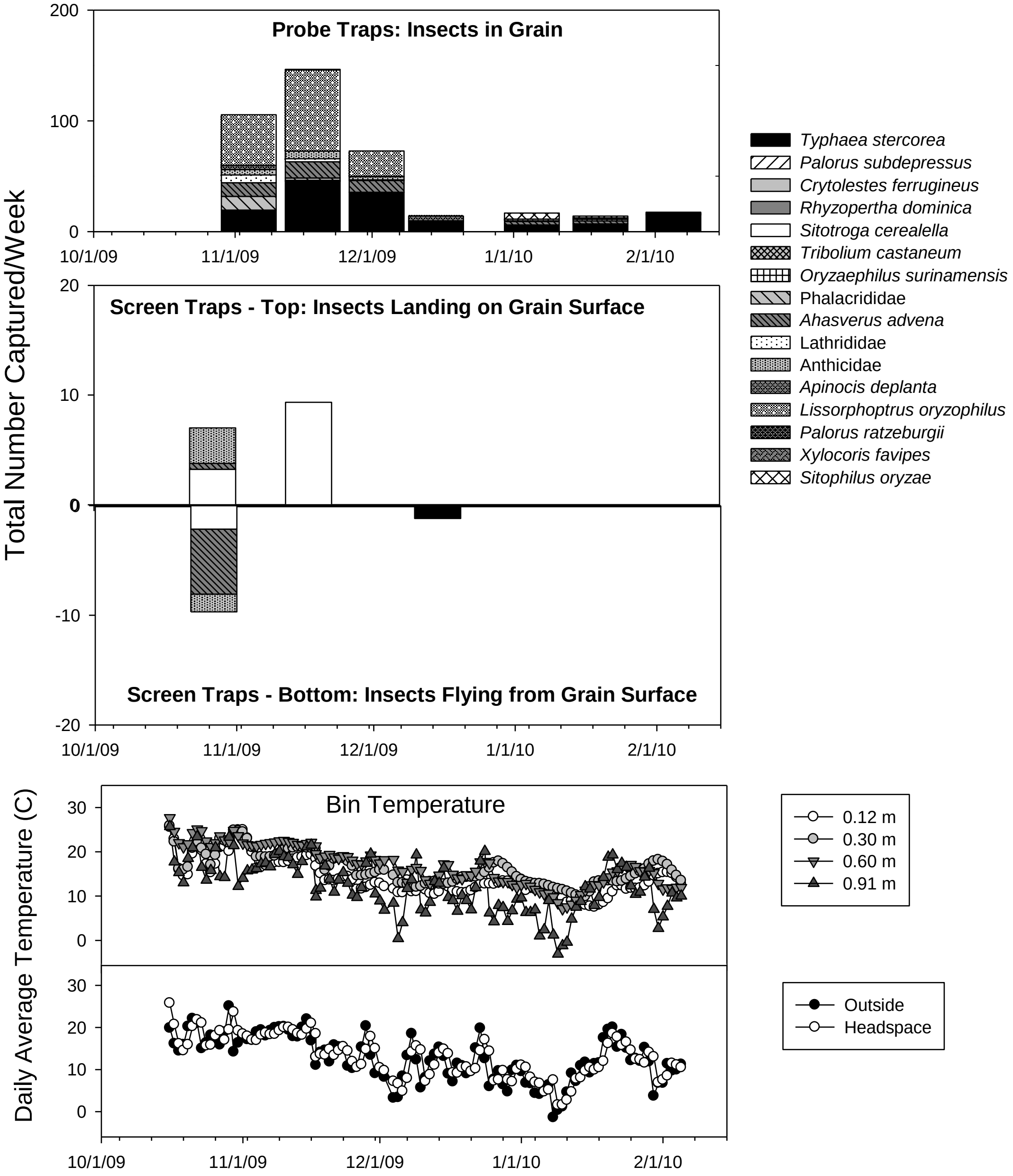

**Figure 3.5. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one; bin 5; loaded 9/19/09; unloaded 2/8/10.**

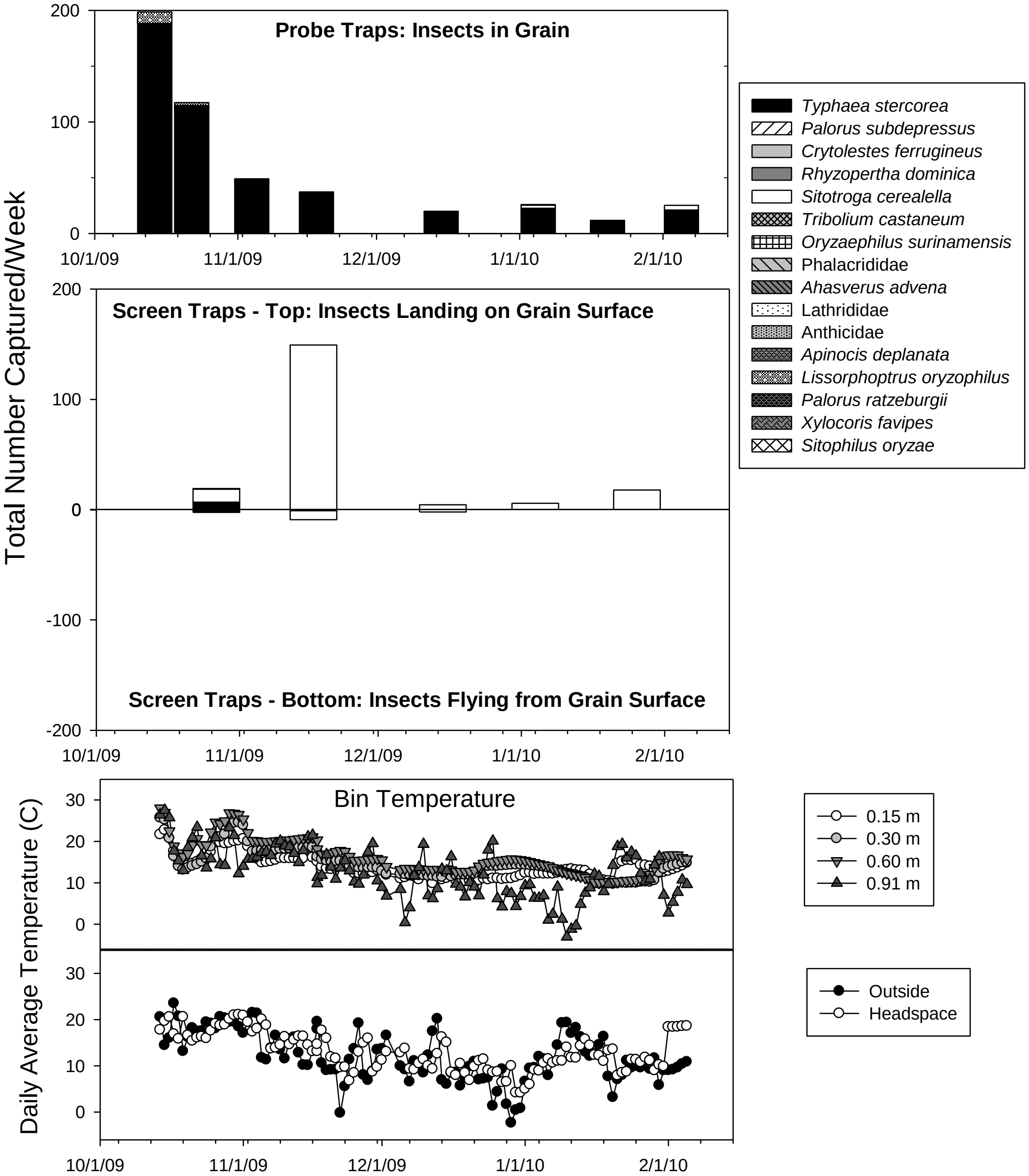

**Figure 3.6 Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season one; bin 6; loaded 8/11/09; unloaded 1/20/10.**

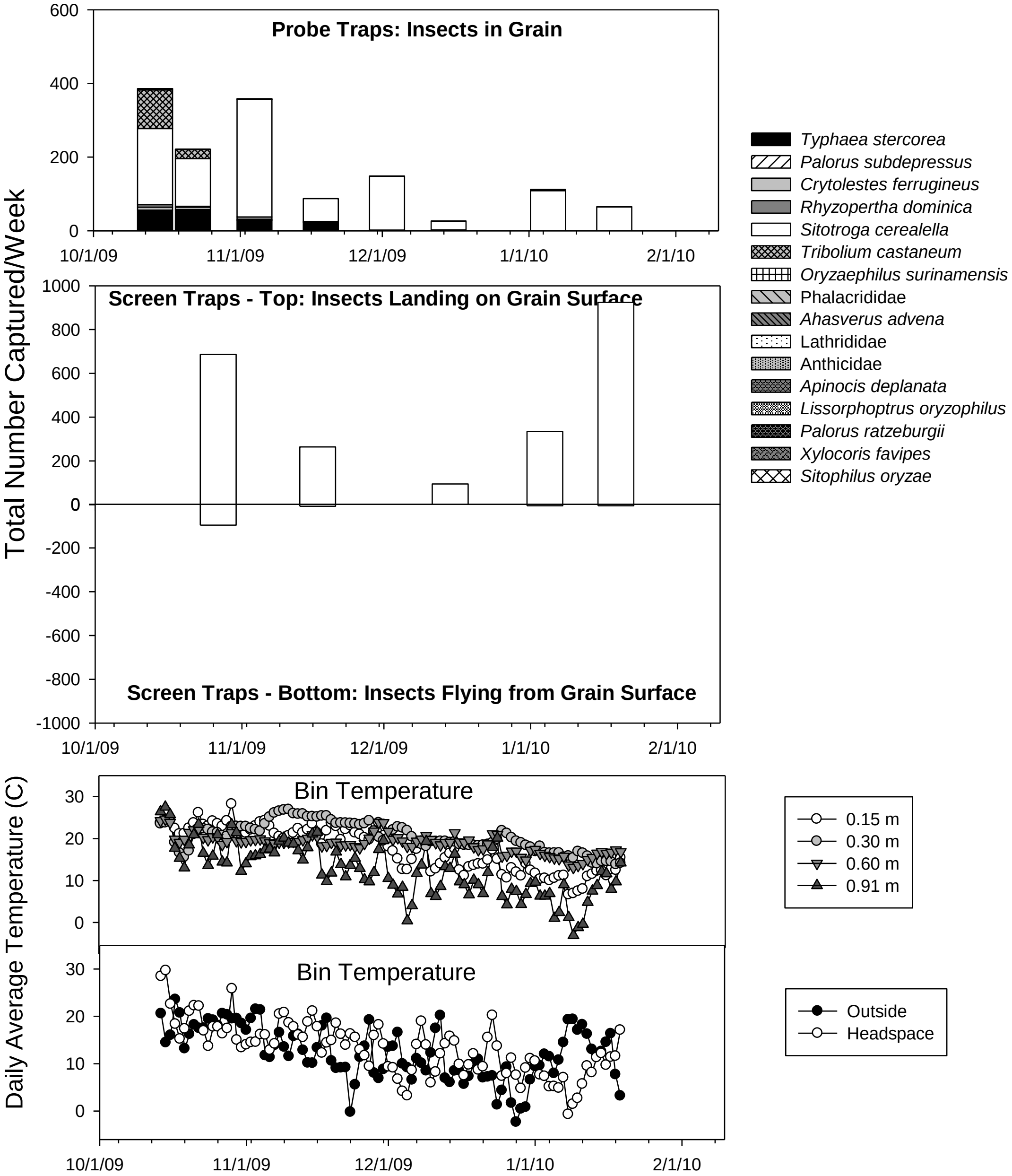

**Figure 3.7. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 1; loaded 9/3/10; unloaded 1/21/11.**

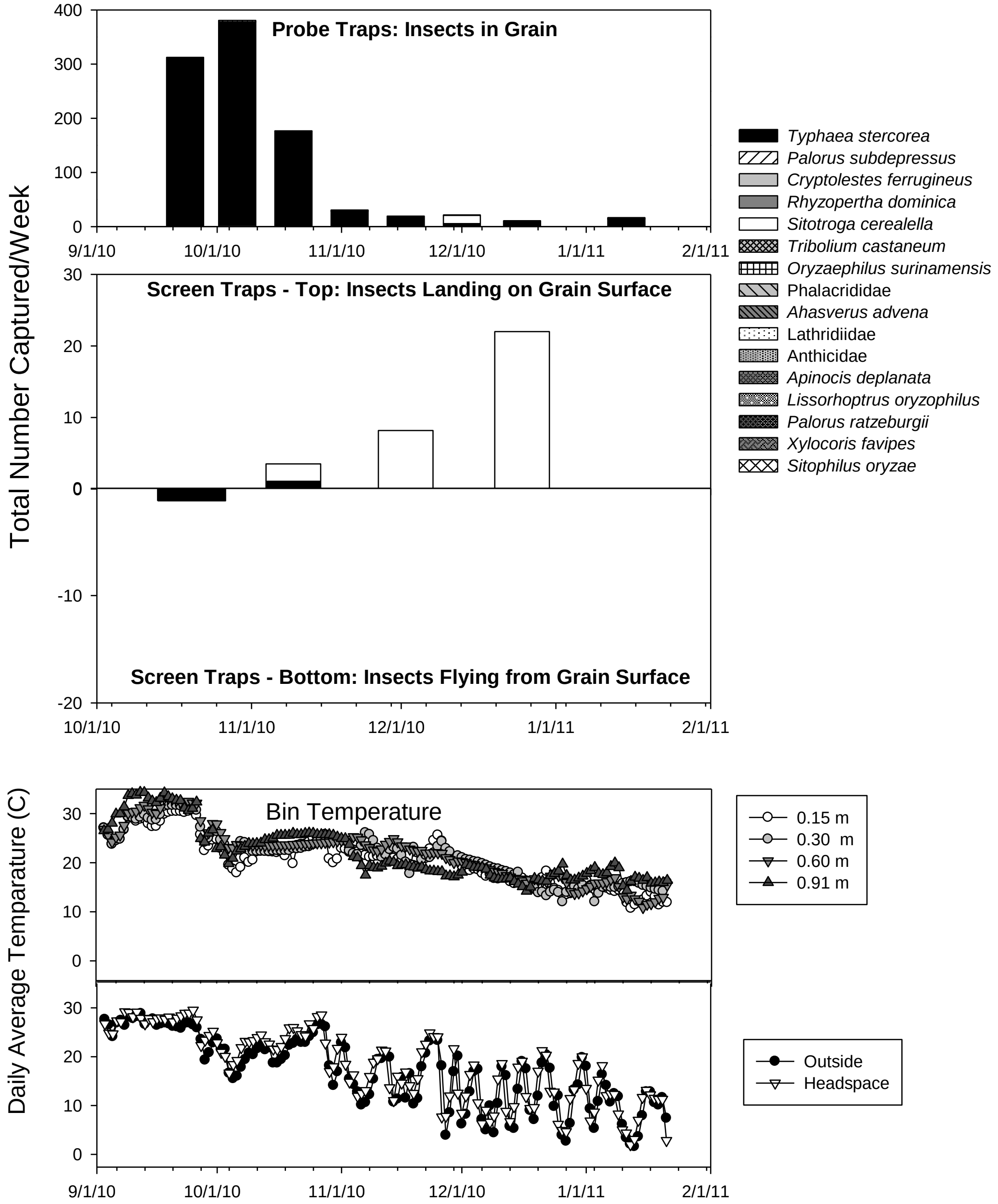

**Figure 3.8. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 2; loaded 9/3/10; unloaded 1/28/11.**

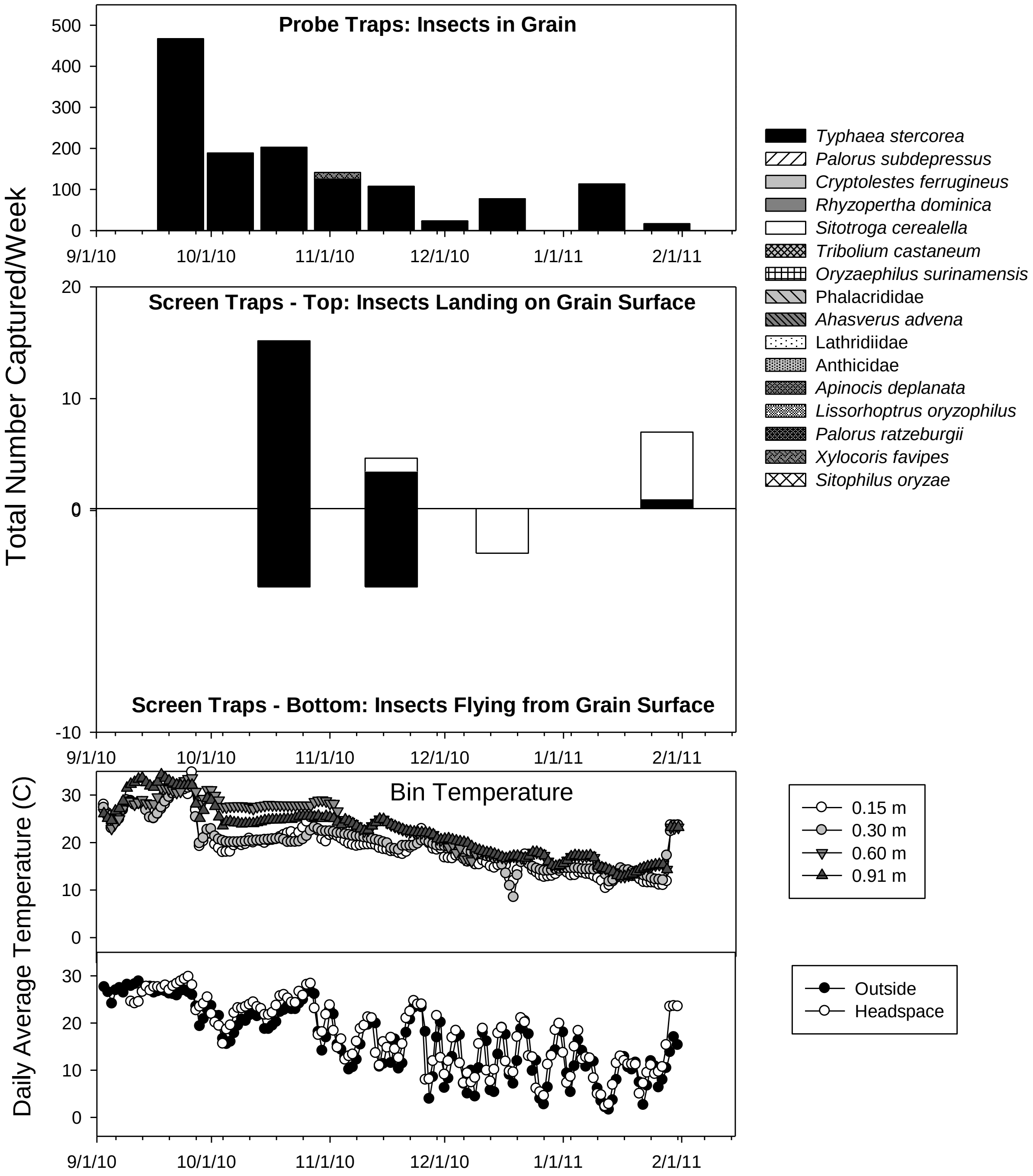

**Figure 3.9. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 3; loaded 9/9/10, unloaded 2/10/11.**

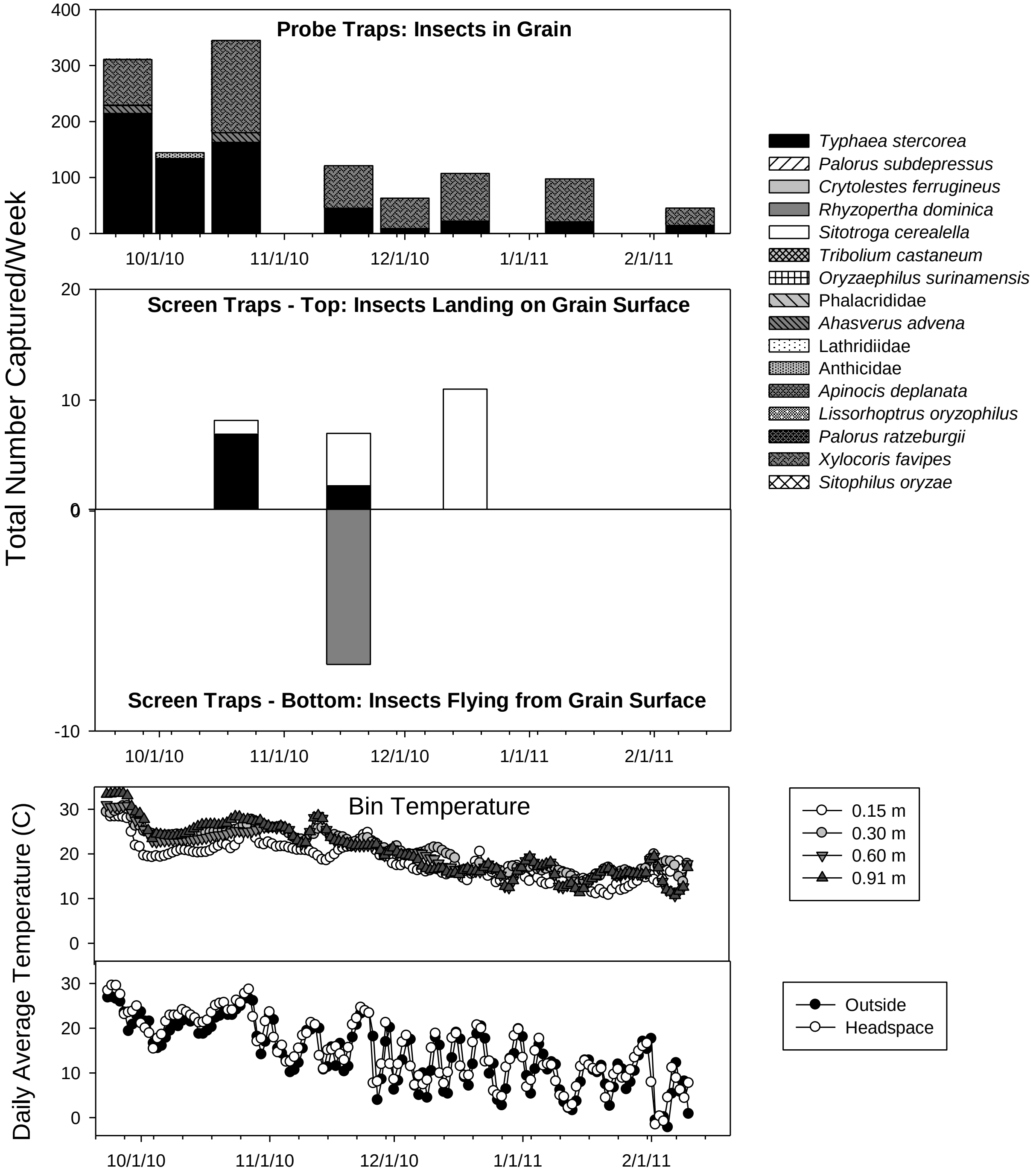

**Figure 3.10. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 4; loaded 10/05/10, unloaded 1/4/11.**

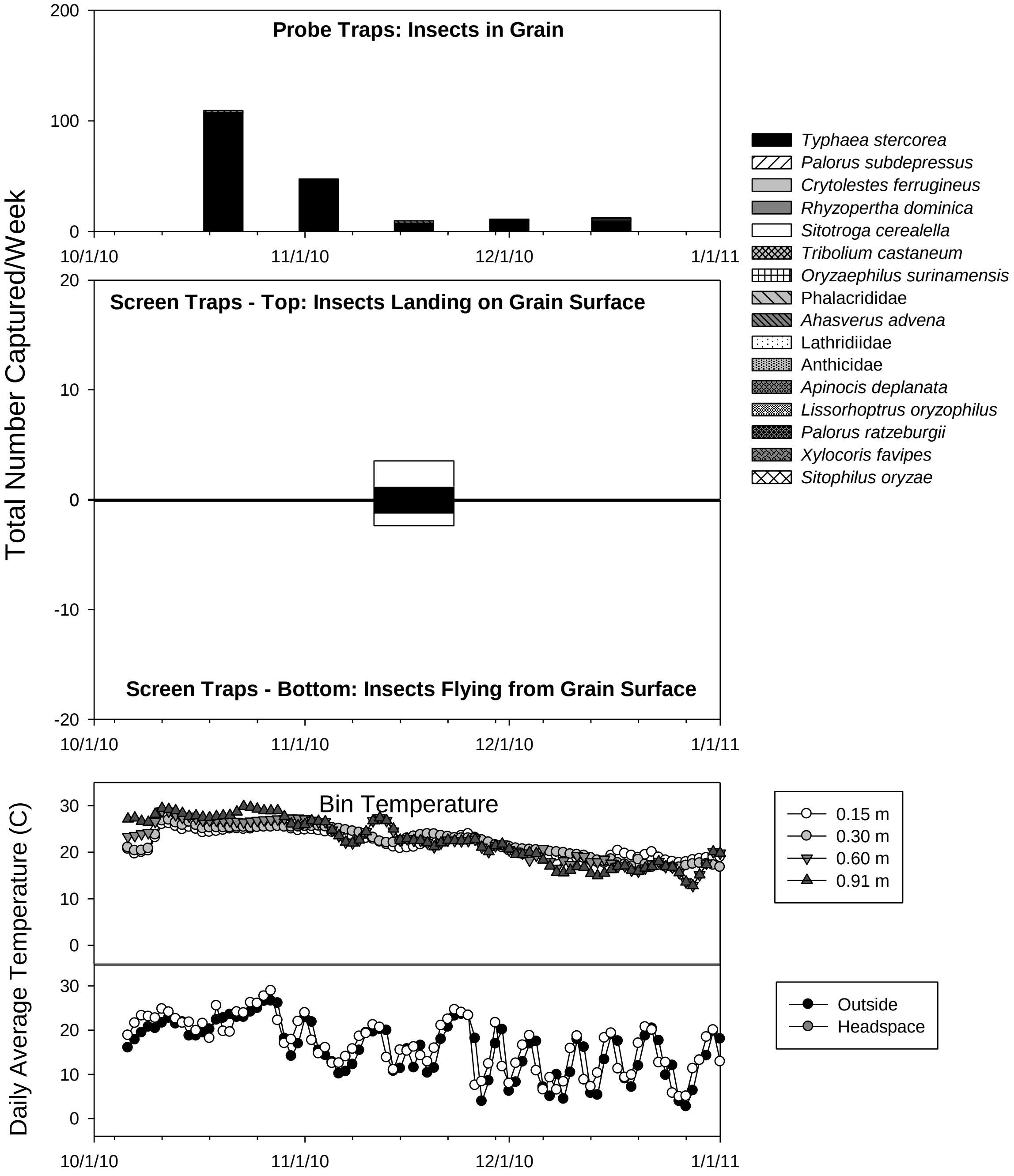

**Figure 3.11. Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 5; loaded 9/05/10; unloaded 1/11/11.**

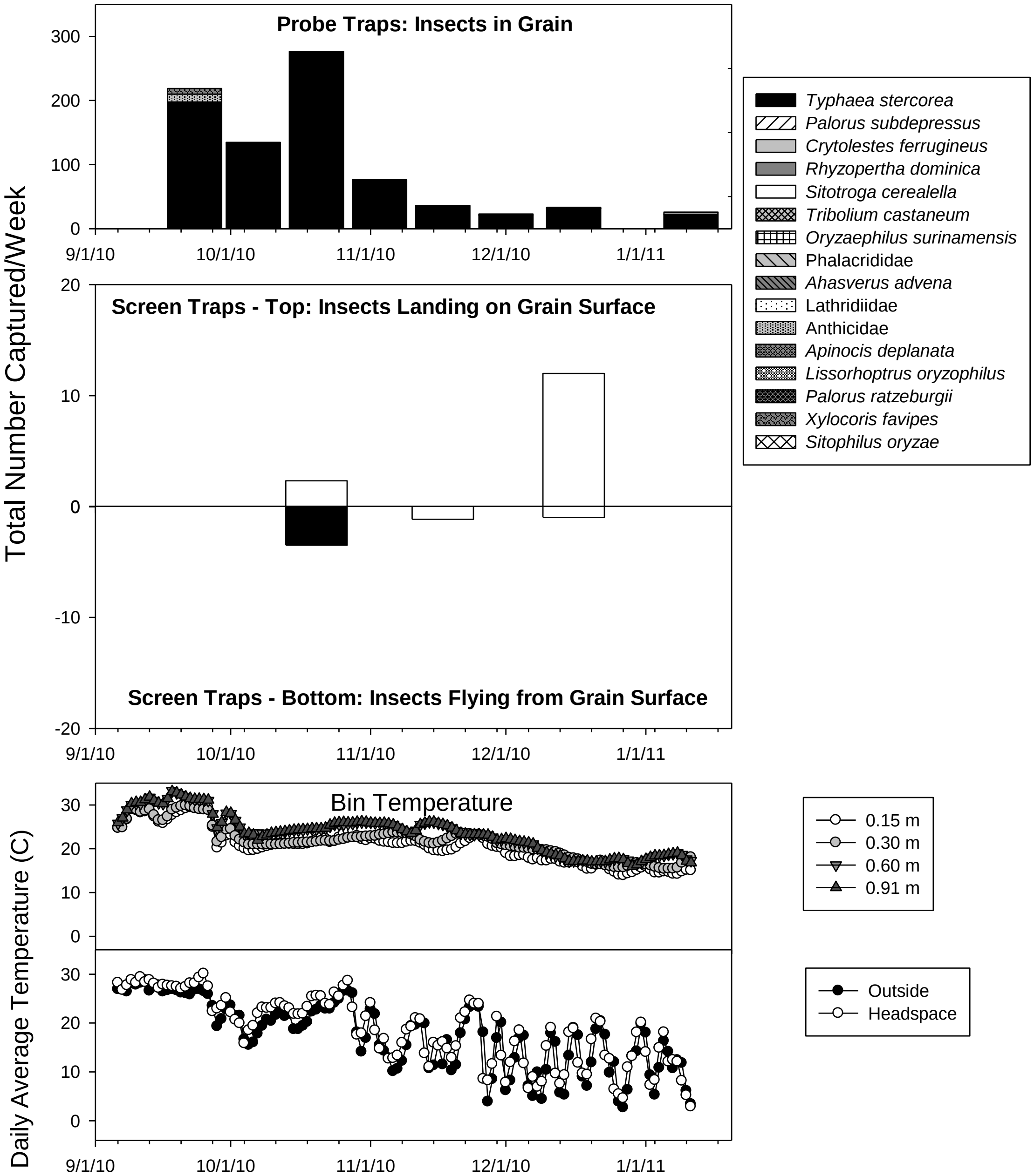

**Figure 3.12 Insects captures in rice storage bin in probe traps placed in grain mass or screen traps placed at the grain surface to detect movement of insects into (Screen Traps - Top) or out of (Screen Traps – Bottom) the grain, and temperature at different depths within the grain, in the headspace of the bin, or in the outside environment: season two; bin 6; loaded 9/06/10; unloaded 2/10/11.**