The rice stink bug, Oebalus pugnax (F.), is a pest of cultivated crops such as wheat, Triticum aestivum L. (Lugger 1900, Forbes 1905, Sailer 1944); rice, Oryza sativa L. (Riley 1882, Webb 1920); corn, Zea mays L. (Forbes 1905, Odgen and Warren 1962); millet, Panicum virgatumum L., (Garman 1891); grain sorghum, Sorghum bicolor (L.) Moench, (Dahm 1942, Hall and Teetes 1981); barley, Hordeum vulgare L.; oats, Avena spp.; and rye, Secale cereale L. (Odgen and Warren 1962). O. pugnax is the most injurious insect pest of heading rice in all rice producing states of the United States (Douglas 1939, Douglas and Ingram 1942, Way 2003), except California (Gianessi 2009). O. pugnax relies on a broad range of graminaceous host species for feeding and reproduction throughout the year. These hosts allow the buildup of populations that eventually migrate into rice (Odgen and Warren 1962).

The abundance of these host species can influence O. pugnax population dynamics (Velasco and Walter 1993). Although Douglas and Ingram (1942) and Odgen and Warren (1962) documented host grass species of O. pugnax, research on the abundance and distribution of O. pugnax relative to the host phenology of host grass species is limited. Additionally, some of the more important host species have recently developed resistance to glyphosate (Roundup, Monsanto Co., St. Louis, MO), a broad spectrum herbicide that is used to manage multiple weed species in agriculture (Orloff et al. 2009). Unfortunately, these host grass species are in close proximity to rice fields, a source of concern among rice growers.

Italian ryegrass, Lolium perenne L. ssp. multiflorum (Lambert); barnyardgrass, Echinochloa crus-galli (L.) P. Beauv.; and Johnsongrass, Sorghum halepense (L.) Pers., have all been reported to have developed herbicide resistance in Mississippi (Allen et al. 1995, Bond and Enbank 2012). As a result, host plant species have become more abundant than they were in the past (Orloff et al. 2009) and O. pugnax injury to rice can be more severe under this situation (Awuni 2013). Host grasses have, therefore, become an important component of the population dynamics of O. pugnax prior to rice heading. In particular, Italian ryegrass is currently widespread across the agricultural landscape in many of the rice producing areas of the southern United States because it is no longer managed with glyphosate applications during the early spring.

In Mississippi, Italian ryegrass and wheat, Triticum aestivum L., are the most common spring hosts when O. pugnax emerge from overwintering. Italian ryegrass
emerges during the fall, begins to flower during early spring, and does not senesce until early summer (Bond and Eubank 2012). During the early summer, O. pugnax will migrate from spring hosts to summer annuals. Summer annuals that have been documented as hosts of O. pugnax include: barnyardgrass, E. crus-galli (L.) Link; Johnsongrass, Sorghum halepense (L.) Link; dallisgrass, Paspalum dilatatum Poir.; and bahiagrass, Paspalum notatum Fluegge (Douglas 1939, Douglas and Ingram 1942). The abundance of these host grass species during summer facilitates dispersal of O. pugnax into rice fields, causing widespread infestations (Douglas 1939, Douglas and Ingram 1942, Swan- son and Newson 1962). Previous research has cited rice as the most preferred host for nymphal development and adult reproduction (Naresh and Smith 1984). O. pugnax will, therefore, abandon all other host grass species to feed on rice (Odglen and Warren 1962, McPherson and McPherson 2000). O. pugnax has a unique lifecycle (Nilakhe 1976) facilitated by overwintering conditions, the availability and succession of numerous cultivated and noncultivated host grass species (Panizzi 1997, Naresh and Smith 1984). Rice growers generally depend on insecticides sprays for O. pugnax management, but improper timing of applications and new immigration into fields could result in poor yields and increased production costs. Therefore, alternative control strategies such as alternate host plant management could play an important role in mitigating the impact of O. pugnax populations in rice fields. Relatively, little work has been conducted to determine the importance of host grasses on the population growth of O. pugnax before dispersal into rice fields. Most of the work on O. pugnax host grass relationships simply reported the grass species that host O. pugnax without relating their relevance to O. pugnax population dynamics (Douglas and Ingram 1942, Odglen and Warren 1962, Panizzi 1997).

The goal of this study was to examine the role of host grass species (cultivated and uncultivated) in the population dynamics of O. pugnax in the Mississippi Delta. Specifically, the study was designed to estimate the relative abundance of O. pugnax on the principal host grass species and identify the most important host grass species that contribute to O. pugnax dispersal into Mississippi rice production fields.

**Materials and Methods**

**Study Area and Sampling Procedure.** O. pugnax was monitored with a standard sweep net (38 cm) on 15 graminaceous hosts in Washington, Bolivar, and Sunflower counties in the central Delta of Mississippi from 4 May until 18 August 2011, and from 12 April to 15 August 2012. O. pugnax nymphs and adults were counted at sampling sites. Host grass species were sampled at weekly intervals from 9:30 to 11:30 am or 2:30 to 4:30 pm, based on host availability. Ten samples of 10 consecutive sweeps were taken on each potential host during each week when it was at a maturity suitable for stink bugs. There were three people that conducted sampling during each sampling period. Sampling pattern depended on the nature and location of host grass species. S. halepense was the only host grass species that was monitored with the sweep net raised above the shoulders. All other host grass species were sampled with the sweep net below the shoulders. Captured O. pugnax were sorted, counted, and placed in 29 by 29 by 29-cm rearing cages (BugDorn, BioQuip Products, Rancho Dominguez, CA) and transported to the laboratory for further studies. Sampling was initiated when host grasses began reproductive development (panicle emergence), the stage suitable for O. pugnax, and was discontinued when ~70% of host grasses had senesced.

**Host Grass Species and Habitats.** Two cultivated crops, T. aestivum and O. sativa, and 13 uncultivated host grass species were identified and monitored at weekly intervals. Host grass species at various reproductive stages (flowering to maturity) were targeted for sampling. This was determined by the physical presence of inflorescences and/or seed forming structures at the time of sampling. Specific sampling locations were selected at random during times when hosts were at a growth stage suitable for O. pugnax sampling. Habitats sampled included roadsides, pasturcelandrainage ditches, and margins of cultivated fields. A habitat was sampled with 10 sets of 10 sweeps. Specimens of each host grass species were collected and transported to the laboratory for identification. Grass specimens were identified, as described by Bryson and DeFelice (2009) and with approval from a resident weed scientist. The relatively short period of panicle development, coupled with chemical and mechanical management of host grasses among some of the sampling locations impacted continued sampling of individual patches over multiple weeks. However, a particular sampling area was determined to be within a 1-km diameter of a central location when sampling was disrupted by management.

**Data Analysis.** Host grass species were categorized according to genera and analysis conducted. A comprehensive analysis comparing all factors and their interactions could not be conducted because of differences in time of host maturity and number of samples conducted per host genus during each week and year. Additionally, weather conditions such as rainfall and temperature were not the same between years (Table 1). As a result, separate analyses were conducted to determine the impacts of year and month. In the first analysis, the numbers of O. pugnax adults and nymphs per 10 sweeps in 2011 were compared with 2012 averaged across all weeks and hosts. Year was considered a fixed effect in the model and sample by year interaction included as random effect. The second analysis compared mean numbers of O. pugnax for each month within each year. Month was considered a fixed effect in the model and the sample by month interaction included as a random effect. Finally, an additional analysis compared O. pugnax among genera within each Julian week and year. Genus was considered a fixed effect in the model and the sample by week interaction was considered random. The means and SEs were evaluated from analysis of the raw data and the
mean separation statistics were evaluated based on analysis of square root transformed data, and reported based on back-transformed means. All analyses were conducted with analysis of variance PROC MIXED (version 9.3; Littell et al. 1996). Degrees of freedom were estimated using the Kenward-Roger method. Means and SEs were calculated using the PROC MEANS statement and means were separated based on the LSMEANS using Fisher’s protected least significant difference with α = 0.05.

## Results

### Sequence of *O. pugnax* on Graminaceous Host Species

There were 15 host grass species (Table 2) in 10 genera that supported the survival, development, and reproduction of *O. pugnax* throughout the sampling periods of 2011 and 2012. The importance of a host was determined by *O. pugnax* density within the week of sampling. Based on this study, *L. perenne* spp. *multiflorum* and *T. aestivum* were the two most important host grass species that supported *O. pugnax* from winter emergence. *L. multiflorum* and *T. aestivum* supported *O. pugnax* populations beginning during week 17 of 2011 and week 15 of 2012 (Table 2). These two genera accounted for 16% in 2011 and 9% in 2012 of the number samples conducted. *Digitaria* spp. and *Echinochloa colona* (L.) Link were the most common and important host grass species during the summer of both years. *E. crus-galli* was limited and was listed as *E. colona*. *Digitaria* spp. and *E. colona* genera together maintained *O. pugnax* populations longer into the season, and accounted ~32% of the samples of *O. pugnax* each during both years. *Digitaria* spp. and *E. crus-galli* both supported *O. pugnax* for 12 wk in 2011 and 14 wk in 2012, respectively (Table 2). There were two host grass species (*Eriochloa acuminata* (J. Presl) Kunth and *Eriochloa contracta* Hitch.) represented in *Eriochloa* in both years. These species together maintained *O. pugnax* for a period of 11 wk each in both years. *S. halepense*, *Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster, and *Paspalum dilatatum* Poir were also important hosts in both years. All other host grass species maintained *O. pugnax* populations for ≤5 wk in both years (Table 2). Most of the host grass species maintained *O. pugnax* populations longer into the season in 2012 than in 2011 (Table 2). *Urochloa texana* (Bukl.) R. D. Webster was not found during 2012.

### Mean Annual and Monthly Abundance of *O. pugnax*

There were no significant difference between mean monthly densities of adult *O. pugnax* per 10 sweeps across hosts in 2011 (*F* = 1.38; *df* = 3, 716; *P* = 0.25; Table 3). However, more nymphs were collected during August 2011 than the other months of 2011 (*F* = 358.7; *df* = 1, 1628; *P* < 0.01; Table 3). In 2012, the mean monthly densities of *O. pugnax* per 10 sweeps collected across host grass species increased significantly as the season progressed for adults (*F* = 37.01; *df* = 4, 905; *P* < 0.01) and nymphs (*F* = 68.86; *df* = 4, 904; *P* < 0.01; Table 3). Densities of *O. pugnax* adults and nymphs were greater during

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### Table 1. Monthly temperature, relative humidity, and rainfall data during sampling period (2011–2012)

| Year | Month | Temperature max (°C) | Temperature min (°C) | RH (max) (%) | RH (min.) (%) | Rainfall (mm) |
|------|-------|----------------------|----------------------|--------------|--------------|--------------|
| 2011 | April | 26.84 | 14.06 | 91.13 | 39.93 | 160.27 |
|      | May   | 25.30 | 16.53 | 90.16 | 41.55 | 70.00 |
|      | June  | 34.89 | 23.04 | 89.60 | 41.00 | 40.13 |
|      | July  | 35.41 | 23.73 | 93.16 | 45.35 | 49.76 |
|      | Aug.  | 35.38 | 23.04 | 93.03 | 40.68 | 61.21 |
|      | Mean  | 32.18 | 20.16 | 91.43 | 41.72 | 351.52 |
| 2012 | April | 25.82 | 13.82 | 91.80 | 41.50 | 106.43 |
|      | May   | 30.88 | 19.03 | 90.63 | 36.87 | 51.56 |
|      | June  | 31.71 | 20.35 | 91.00 | 41.52 | 162.31 |
|      | July  | 33.02 | 23.48 | 94.32 | 50.60 | 116.08 |
|      | Aug.  | 33.78 | 21.11 | 94.15 | 38.57 | 108.97 |
|      | Mean  | 31.25 | 19.59 | 92.37 | 41.86 | 545.34 |

Source: Delta Research and Extension (DREC) weather station.

### Table 2. Host grass species, Julian week sampled, and number of samples on host grass species during sampling period in and around the Delta Research and Extension Center (DREC), Stoneville, MS in 2011 and 2012

| Host grass species | 2011 | | | 2012 | | |
|-------------------|------|------|------|------|------|------|
| Wheat, Triticum aestivum L. | | | | | | |
| Ryegrass, Lolium perenne L. ssp. multiflorum (Lam.) Husnot | | | | | | |
| Crabgrass, Digitaria sp. Haller | | | | | | |
| Johnsongrass, Sorghum halepense (L.) Link | | | | | | |
| Prairie cupgrass, Eriochloa contracta Hitch. | | | | | | |
| Southwestern cupgrass, Eriochloa acuminata (J. Presl) Kunth | | | | | | |
| Jungrergic, Echinochloa colona (L.) Link | | | | | | |
| Bahiagrass, Paspalum notatum Flugge | | | | | | |
| Dasilgrass, Paspalum dilatatum Poir | | | | | | |
| Yellow foxtail, Setaria pumila (Poir) Roem & Schult. | | | | | | |
| Texas nutlet, Urochloa texana (Bukl.) R. D. Webster | | | | | | |
| Browntop nutlet, Urochloa ramosa (L.) Nguyen | | | | | | |
| Broadleaf signalgrass, Urochloa platyphylla (Munro ex C. Wright) R. D. Webster | | | | | | |
| Rice, Oryza sativa L. | | | | | | |

2011: Start week 17, End week 17, No of weeks 4; 2012: Start week 15, End week 15, No of weeks 4.
August 2012 compared with any other month during that year. The overall average annual densities of *O. pugnax* across host grass species during the study period from all counties recorded significantly more adults (*F* = 358.7; df = 1, 1628; *P* < 0.01) and nymphs (*F* = 115.1; df = 1, 1627; *P* < 0.01) per 10 sweeps in 2011 compared with 2012 (Table 3).

**Table 3. LS Mean (SEM) monthly and annual densities of *O. pugnax* per 10 sweeps collected around Washington, Sunflower, and Bolivar Counties 2011 and 2012**

| Month  | Adults per 10 sweeps | Nymphs per 10 sweeps |
|--------|----------------------|----------------------|
|        | 2011 | 2012   | 2011 | 2012 |
| April  | 1.54a | 1.70a | 2.83b | 3.93b |
| May    | 15.3a | 1.17a | 0.56c | 4.13a |
| June   | 13.1a | 1.13a | 0.22b | 0.39a |
| July   | 14.5a | 2.03a | 0.16b | 0.43c |
| Annual | 14.7a | 0.68a | 3.90b | 4.04b |

*Means within the same column followed by the same lower case letter are not significantly different (α = 0.05). Annual means within a row for each *O. pugnax* stage with the same upper case letter are not significantly different (α = 0.05).*

Discussion

The total number of *O. pugnax* sampled across host grass species was greater in 2011 compared with 2012. Because densities were high throughout 2011, it is likely that overwintering survival was high during the winter of 2010–2011 compared with the winter of 2011–2012. There were differences in weather conditions between the years. It could also be argued that abiotic conditions better favored *O. pugnax* activities in 2011 than in 2012. The average maximum and minimum temperatures in 2011 were 59.59 and 58.29°F, compared with 58.25 and 67.26°F in 2012, respectively. Temperatures were all time higher during summer in 2011 than in 2012, as indicated in Table 1. Precipitation during the study period was greater in all months for 2012 than for 2011. Constant cold conditions resulting from wet environs can result in reduced insect metabolism. Therefore, 2011 was much a favorable year for arthropods activity than in 2012. Although the relationship between insect outbreak and microclimate has not been well established, the relationship seems compelling (Haile 2000). Environmental factors, primarily extremes in temperature and precipitation, have been documented to cause recurring outbreaks in insect populations of pest species. These conditions may have accounted for the larger numbers of *O. pugnax* population recorded in 2011 compared with 2012.

Although the densities of *O. pugnax* collected from host grass species varied between years, the periods during which grasses were used as hosts were similar in both years. Most stink bugs, including *O. pugnax*, are polyphagous and feed on a broad range of cultivated and uncultivated host plants (Panizzi 1997, Jones and Sullivan 1982). In the current study, the general dynamics of both adult and nymph *O. pugnax* populations indicated that host grass species can be categorized into four groups. The first category includes *Lolium* and *Triticum* that supported *O. pugnax* survival, development, and reproduction early in the spring. These host grasses are winter annuals that germinate in the fall and bear fruiting structures during the early spring in both years. Densities on *Triticum* were lower compared with *Lolium* during the early spring, but both species are important in supporting *O. pugnax* from overwintering. *L. multiflorum* has become one of the most dominant host grass along roadsides, ditches, and fallow fields from late winter to early summer. This may be the result of its difficulty to control owing to resistance to the broad-spectrum herbicide glyphosate (Bond and Eubank 2012).
The second group includes *Digitaria*, *Echinochloa*, and *Eriochloa* genera that sustained *O. pugnax* populations during the summer. *Digitaria* is an important transitional host because it supported *O. pugnax* just after *Lolium* and *Triticum* and at least 2 wk earlier than the other summer annuals. *E. crus-galli* was rarely found, and if found was in low densities along drainage habitats and field margins. *E. colona* was more abundant in and around Mississippi rice production fields than *E. crus-galli*. Perhaps, the most important role of *E. colona* is its ability to effectively compete with rice for resources in rice fields, and the ability to mimic rice at the seedling stage. When not detected early in rice fields, *E. colona* can attract *O. pugnax* into rice fields even before rice panicles begin to head because they are early maturing than rice. An important role of *Echinochloa* was its support for nymphal development as nymphal densities on *Echinochloa* were often as high as or higher than on any other host.
The third group of host genera included *Paspalum, Sorghum,* and *Setaria* that sporadically hosted *O. pugnax,* so may not be critical factors impacting *O. pugnax* population dynamics. Although large numbers of *O. pugnax* adults were captured on *S. halepense,* it was the least supportive for *O. pugnax* nymphs throughout the 2-yr study. This may be an indication of non-suitability for nymphal development. Garman (1891) observed *O. pugnax* feeding on several species of *Setaria* and other grass spp., consistent with the current study. The fourth group includes three species of *Echinochloa*, *Urochloa* *ramosa,* and *Urochloa texana,* which were generally observed in senescing corn fields or along abandoned cropped fields. This group appeared to serve as transitional hosts for *O. pugnax* populations prior to overwintering. Hall and Teetes (1981) and other grass spp. consistent with the current study.
previously reported *Urochloa fusca* (Swartz), and *U. texana* as hosts of *O. pugnax* during the months of June and July. But, in this study, these host grasses appear to support *O. pugnax* populations that overwinter. Because of foliar insecticide sprays for *O. pugnax* control in rice fields, limited sampling was conducted in rice, but other research showed that rice is preferred for feeding (Awuni et al. 2014).

The sequence of host grass availability was important because the preferred feeding sites of *O. pugnax* change over time, so a succession of hosts is required for successive generations during any crop season (Panizzi 1997, Borges et al. 2011). Douglas (1939) listed seven host grass species utilized by *O. pugnax* in Louisiana, but noted that the list was incomplete. In a later development, Douglas and Ingram (1942) identified 10 host grass species of *O. pugnax*, while Odglen and Warren (1962) listed 7 cultivated and 10 uncultivated host species in Arkansas. In this study, 2 cultivated and 13 uncultivated host grass species representing 10 genera were identified as important for *O. pugnax* survival and reproduction in Mississippi. Admittedly, this may not be an exhaustive list of host grass species fed on by *O. pugnax* in Mississippi. Odglen and Warren (1962) observed that these host grasses could support two to three generations of *O. pugnax* before rice starts to head.

The preference of *O. pugnax* among host grass species remains a subject of debate. Douglas and Ingram (1942) reported vasegrass, *Paspalum turvilei* Steud., as the most preferred host of *O. pugnax* amongst wild host grass species. In contrast, Odglen and Warren (1962) reported *E. colona* amongst the uncultivated host grass species. In a related study, Awuni et al. (2014) reported *E. colona* as the most preferred of the 13 host grass species in a preference and suitability tested.

The current control of *O. pugnax* largely depends on in-crop treatment with broad-spectrum insecticide sprays that may increase costs of production and harm the environment (Sudarsono et al. 1992). Manipulation of host grass species could reduce production costs if implemented in a timely manner. Any management strategy aimed at disrupting or reducing host abundance may impact *O. pugnax* populations. This can be accomplished through the use of integrated pest management program, which involves multidisciplinary approach to minimizing rice field infestations and reducing treatment costs. Although Douglas (1939) argued that moving host grasses could increase *O. pugnax* infestations in adjoining rice fields, Webb (1920) noted that moving grasses around rice fields in a timely manner could reduce rice injury from *O. pugnax* infestation. The key is moving host grasses before flowering grass panicle starts to head. This means host management could be an important component of *O. pugnax* management. Destruction of spring and early summer hosts of *O. pugnax* could reduce *O. pugnax* populations later in rice. Late-season habitats that can increase *O. pugnax* populations prior to overwintering could be destroyed similarly, reducing the number of *O. pugnax* adults that overwinter.

In conclusion, rice growers are well aware of the economic significance of *O. pugnax* infestation in rice and the role of host grass species in the abundance of *O. pugnax*. There is, however, need for improved awareness of the relationship between *O. pugnax* and host grasses. This is particularly important because of reported herbicide resistance of some principal host grasses such as *E. colona*, *L. perenne*, and *S. halepense* that are not only prevalent in the landscape, but utilized by *O. pugnax* in Mississippi.

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