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Acridid ecology in the sugarcane agro-ecosystem in the Zululand region of KwaZulu-Natal, South Africa

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Abstract

Grasshoppers and locusts are well known crop and pasture pests throughout the world. Periodically they cause extensive damage to large areas of crops and grazing lands, which often exacerbate food shortage issues in many countries. In South Africa, acridid outbreaks rarely reach economic proportions, but in sugarcane plantations, localized outbreaks of native acridid species have been reported for the last eight years with increasing frequency and intensity in certain areas. This study was undertaken from May 2012 to May 2013 to identify the economically important acridid species in the sugarcane agroecosystem in these outbreak areas, to monitor seasonal activity patterns, to assess sampling methods, and to determine the pest status of the major species through damage ratings. Five acridid species of particular importance were identified: *Nomadacris septemfasciata* (Serville), *Petamella prosternalis* (Karny), *Ornithacris cyanea* (Stoll), *Cataloipus zuluensis* Sjötedt, and *Cyrtacanthacris aeruginosa* (Stoll). All species are univoltine. *Petamella prosternalis* was the most abundant species and exhibited a winter egg diapause, while *N. septemfasciata*, the second most abundant species, exhibited a winter reproductive diapause. *Petamella prosternalis* and *N. septemfasciata* were significantly correlated with the damage-rating index, suggesting that these two species were responsible for most of the feeding damage found on sugarcane. This study, for the first time, identified the acridid species complex causing damage to sugarcane in the Zululand area of KwaZulu-Natal, South Africa, and documented their population characteristics and related damage. These data are important information on which to base sound integrated pest management strategies.

Keywords

Cataloipus zuluensis, *Cyrtacanthacris aeruginosa*, damage rating, management, *Nomadacris septemfasciata*, *Ornithacris cyanea*, outbreaks, *Petamella prosternalis*, population surveys

Introduction

Grasshoppers and locusts (Orthoptera: Acrididae) attack sugarcane in various parts of the world, such as Indonesia (Lecoq and Sukirno 1999), West Africa (Maiga et al. 2008), India (Easwaramoorthy et al. 1989), and Africa (Whellan 1968, Bakker 1999, Price and Brown 1999). These insects defoliate plants, thereby reducing their photosynthetic capabilities (Williams et al. 1969, Easwaramoorthy et al. 1989). In southern Africa, three major plagues of the red locust, *Nomadacris septemfasciata* (Serville) (Orthoptera: Acrididae: Cyrtacanthacridinae), have occurred in recent history (Bahana 1999). The last one, between 1929 and 1944, affected most of Africa south of the equator. During this plague, the northern part of KwaZulu-Natal Province of South Africa was heavily invaded and, in 1934, cost the sugarcane industry approximately £1 million (De V. Minnaar 1990). This report has been, so far, the only documented acridid pest attack on sugarcane in South Africa. Locust outbreaks on other crops and pastures remain a serious problem in the southern African region, especially outbreaks of brown locust, *Locustana pardalina* (Walker) (Acrididae: Oedipodinae), and *N. septemfasciata*, which still threaten sustainable agricultural production to this day (Lomer et al. 1999, Price and Brown 1999). In South Africa, sugarcane-growing areas lie within the invasion area of these two aforementioned locust species (Whellan 1968). Although there are no recognized red locust outbreak areas in South Africa (Bahana 1999), it is mentioned as an occasional problematic species along the eastern seaboard of KwaZulu-Natal (Faure 1935, Picker et al. 2004). There have been no major outbreaks since 1944, possibly because of our improved knowledge of locust outbreak dynamics, insecticide technology, application techniques, and intervention strategies (Whellan 1968, Price and Brown 1999, Bahana 2000, Lecoq et al. 2011).

Grasshopper outbreaks, on the other hand, have occurred sporadically in southern Africa and, apart from the elegant grasshopper *Zonocerus elegans* Thunberg (Orthoptera: Pyrgomorphidae), which attacks a wide range of wild and crop plants (Nyambo 1991), little information is available for other species. Grasshoppers do not have gregarious habits and therefore do not swarm and migrate even in years of mass outbreaks. They remain pests of purely local importance with no immediate threat to neighboring districts

(Uvarov 1928). Grasshoppers also feed on the leaves of sugarcane, thereby affecting the photosynthetic capability of the plant (Easwaramoorthy et al. 1989). When infestations are high, defoliation may be so serious that only the mid-rib of the plant is left.

Population surveys have generally been used to estimate animal numbers in the field for conservation purposes (Gardiner et al. 2002) but also for studies relating to pest species (O'Neill et al. 2003). In South African sugarcane, population densities and related damage have been reported based on qualitative visual estimates and opinions, rather than quantitative data. Quantitative population surveys based on rigorous capture methods are therefore needed to gain an accurate understanding of pest ecology (Clarke 1948, Southwood and Henderson 2000). However, over the last ten years sugarcane has increasingly come under attack by what was locally referred to as "grasshoppers" in the northern parts of KwaZulu-Natal, generally referred to as "Zululand". Control measures applied against them during this period were ineffective and the identity of the species was unknown, nor was their population phenology. Furthermore, a quantified measurement of actual crop damage was not known. This paper aims to address these shortcomings and provide data on which to base a structured Integrated Pest Management (IPM) program.

Methods

Site descriptions.—Population surveys took place in the Empangeni region of KwaZulu-Natal, South Africa (28°44'56.74"S; 31°53'59.24"E) from 30th May 2012 until 30th May 2013. Four farms, which previously reported significant damage and high population densities, were chosen as study sites. Magazulu farm (Tedder) (28°44'9.54"S, 31°52'16.60"E) is situated within 2 km of Empangeni town and was the most southerly site surveyed. GSA farms (28°40'54.94"S, 31°54'51.98"E) and Crystal Holdings (28°40'0.50"S, 31°54'47.37"E) are situated close to each other, roughly 8 km from Empangeni town, and Jengro (28°37'30.84"S, 32°0'52.68"E) was the most northerly site, situated roughly 18 km from Empangeni town.

Sampling methods.—Population surveys were completed on each farm once a week from May 2012 to May 2013. When the sugarcane was young (3–6 months old), conventional sweep netting was used as it allowed the standard 180° sweep to be done (see Gardiner et al. 2005). However as the sugarcane got taller (above hip height) standard sweep netting became impractical and this method was adapted to drive netting. Drive netting entailed driving at a standard speed (20 km/hour) along the edges of sugarcane plantations while holding an insect net (Bugdorm cages and traps: 60 cm diameter, Product # DC0005, Taiwan) parallel to the soil surface, 1.5 m off the ground, out the window of the vehicle for five minutes and along a specific route (Fig. 1). From May 2012, drive netting was used to catch adult fliers. Mean sugarcane age at the start of the survey (May 2012) was five months.

The route (Fig. 1) consisted of five 100 m transects completed on each farm. This method was used because tall sugarcane forms dense stands and has a closed canopy which makes conventional sweep netting within the sugarcane field impossible as movement of the net is restricted (Bomar 2001). Due to sugarcane harvesting operations, which started in July 2012, drive netting was not possible because acridid populations dispersed more widely over the more open survey area. A visual line transect method was used in the harvested sugarcane in order to maintain sampling accuracy. This method was used from the beginning of August until the end of November 2012 and involved walking five 100 m transects per farm, which were measured using a Garmin global positioning system (GPS). Line transects were completed as close as reasonably possible to drive netting transects. A single transect involved walking 100 m between a sugarcane row while counting each acridid that was disturbed in the row in which the counter was walking and the rows on either side of the counter (i.e., three rows – a width of approximately 3 m). A handheld tally counter (Upgreen counters, UK) was used to record the number of grasshoppers disturbed per transect, which was then added to the total amount for all five transects per farm. At the beginning of November 2012, a new generation of hoppers started to emerge and sweep netting was done along the same walked transects as noted above during visual transects, as described in Gardiner et al. (2005) (Table 1).

Table 1. Summary of survey methods used to measure acridid abundances during population surveys on four sugarcane sites and associated natural habitats from May 2012 to May 2013.

Sampling method	Period of sampling (start and end date)		Age of cane
Drive netting	30-May-12	12-Sep-12	8 months
Visual transects	20-Sep-12	03-Dec-12	12 months
Sweep netting	21-Nov-12	10-Jan-13	3 months
Drive netting	17-Jan-13	15-May-13	5 months

Data collection.—During each field trip, rainfall and temperature were recorded for that day. An attempt was made to conduct field trips only during sunny, dry days in order to minimize sample bias due to climatic factors. One area on each farm where acridid population densities were high was selected as the designated survey site for that farm. Acridids obtained from sweep netting were stored separately per site and brought back to the laboratory alive for identification and counting. Once in the laboratory, they were either killed by freezing or 'cooled' to aid counting. For visual transects, disturbed individuals were identified and recorded without being caught. Collected individuals were sorted into morphologically similar groups, and reference material was identified by a specialist (Corinna S. Bazelet).

DNA Extraction.—The acridid species identified using morphological characters were molecularly DNA barcoded (using the CO1 gene) in the biotechnology section at the South African Sugarcane Research Institute (SASRI). DNA was extracted from the muscle of the hind femur, using the KAPA Express Extract DNA Extraction kit (Kapa Biosystems, South Africa) according to the manufacturer's instructions.

PCR using Cytochrome Oxidase gene primers.—PCR amplification was conducted using the KAPA 2G Robust PCR Kit (Kapa Biosystems, South Africa) with 1µl DNA template. The final reaction conditions were as follows: 1X Kapa2G Buffer A, 0.2 mM dNTP mix, 0.5 µM each COI Forward and COI Reverse primer and 0.5 units Kapa2G Robust DNA Polymerase.

The DNA primer sequences were:

COI Forward – 5'AATTGGGGGGTTTGGAAATTG3'

COI Reverse – 5'GCTCGTGTATCAACGTCTATTCC3'

PCR reactions were conducted in an Applied Biosystems Veriti Thermal Cycler using the following thermal cycling profile: 94°C for 2 min, followed by 35 cycles of 94°C for 30 sec, 55°C for 50 sec, and 72°C for 90 sec. Final extension was at 72°C for 10 min. PCR products were purified using the DNA Clean and Concentrator kit (Zymo Research, USA) according to the manufacturer's instructions.

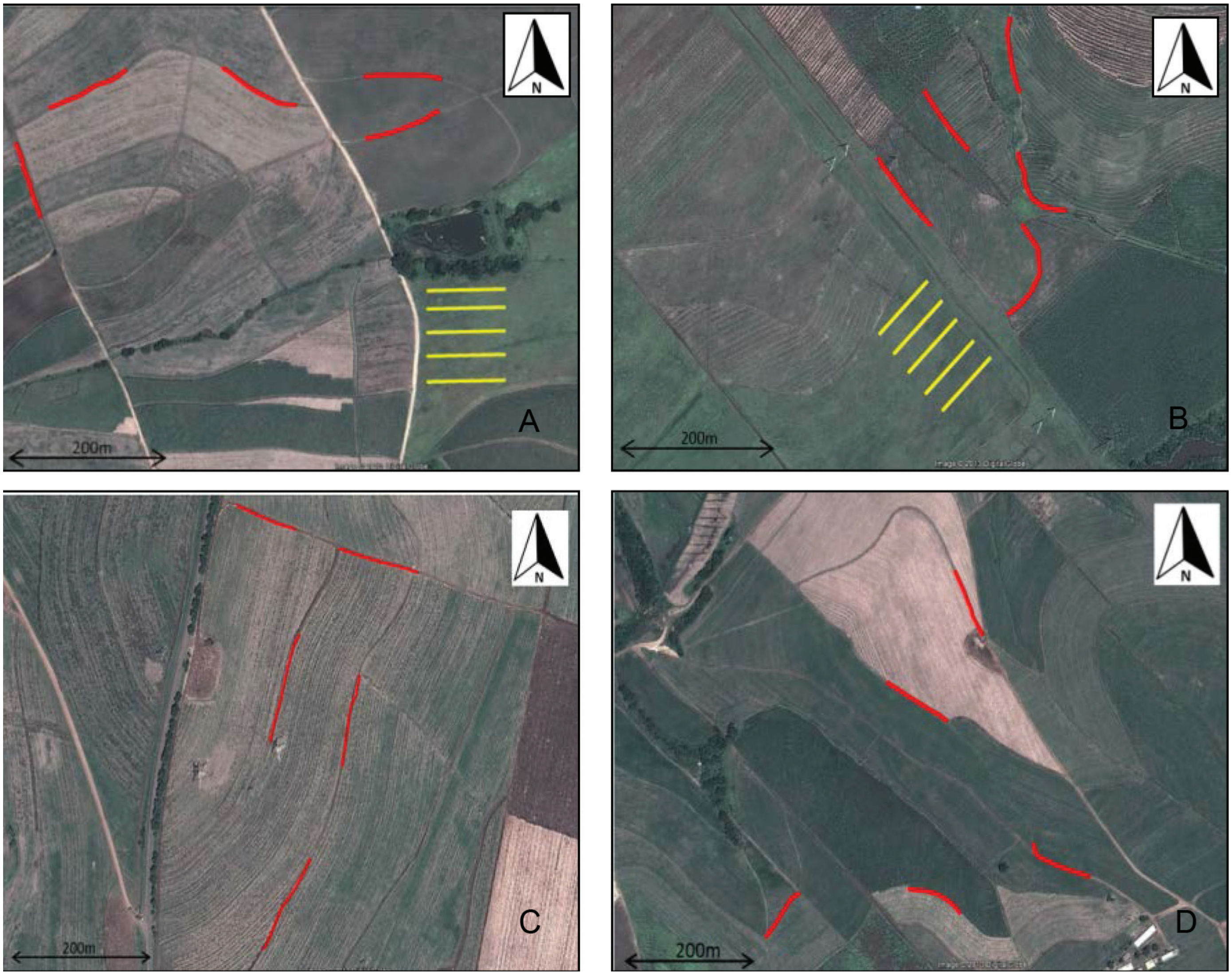

Fig. 1. Aerial view of four farms where surveys took place indicating the five 100 m transects per farm (red lines). Yellow lines indicate the two survey areas in natural habitats. **A**. Tedder (Magazulu) farm; **B**. Crystal Holdings; **C**. GSA farm; and **D**. Jengro.

DNA sequencing was conducted using the BigDye Terminator v3.1 Cycle Sequencing kit (Applied Biosystems, USA) according to the manufacturer's instructions. Sequencing reactions were conducted in an Applied Biosystems Veriti Thermal Cycler using the BigDye Terminator v3.1 kit recommended thermal cycling profile. Sequencing products were purified using the BigDye XTerminator Purification Kit (Applied Biosystems) according to manufacturer's instructions.

Uploading of DNA sequences to online databases.—After obtaining good CO1 sequences, a search on two DNA barcoding websites, namely, BOLD systems (www.boldsystems.org) and the National Centre for Biotechnology Information (www.ncbi.nlm.nih.gov) indicated that none of the species' DNA had been submitted to these databases. The sequences were thus submitted to BOLD systems and Genbank.

Damage rating estimate.—The level of leaf damage due to grasshopper feeding was estimated on a weekly basis to generate a damage-rating index for the period of May 2012–May 2013. During weekly population surveys, five random sugarcane stools (the underground stubble from which the plant is grown) within the sugarcane survey sites were chosen and a damage rating from 1–5 was estimated as the percentage of leaf area eaten on the youngest top five green leaves of a randomly chosen stalk in the stool (Table 2).

Table 2. Criteria used as a guideline to assess damage in order to obtain a damage-rating index to correlate against population abundance data.

Rating	% damage rating
0/5:	0
1/5:	1–20
2/5:	21–40
3/5:	41–60
4/5:	61–80
5/5:	81–100

The five values per transect were then averaged to get a mean damage rating per farm. The four mean weekly damage ratings were combined and averaged to get a monthly damage-rating index and then plotted against the other farms over the entire year.

Acridid surveys in surrounding grassland (natural habitat).—Grassland surveys were completed as a means of comparing grasshopper population densities and species composition in grassland sites compared to sugarcane survey sites. Four sites of natural grassland adjacent or nearby to each of the sugarcane survey sites (approximately 1 km from the sugarcane sites) on each farm were sampled for five months from October 2012 to February 2013. Due to unforeseen circumstances, two of the grassland survey sites had to be abandoned, therefore only two grassland sites remained from 21 November to 17 January (seven weeks). During this period, all acridid species sampled were in the hopper stage. Grassland surveys were completed using the same sweep net method as in the sugarcane study sites. Five 100 m transects were walked per site while sweeping the net over the top half of the grass sward in an 180° arc. Captured specimens were placed in separately marked tubs and brought back to the laboratory for identification and counting.

Data analysis.—Rank abundance curves were plotted, calculating a log abundance value that designated each species a ranking from 1–5 according to their total abundance in sugarcane sites. Monthly relative abundance (total count for all species by individual count for each species) was calculated as a percentage in order to correlate the relative abundance of acridid population densities with observed damage. Gamma rank correlation analysis was performed, which is preferable over the Spearman's R analysis as the data contained many tied observations, which the Gamma analysis explicitly accounts for. Where a correlation between species abundance and the damage-rating index was found, a pairwise comparison was conducted. All analyses were completed in Statistica 11.0 (StatSoft Inc., Tulsa, OK, USA). To compare whether farms were associated with any particular species of grasshopper, a simple correspondence analysis, with grasshopper species as column variables and farms as row variables, was used. Likewise, a simple correspondence analysis was also used to compare habitat type (sugarcane vs. grassland) with grasshopper species over a seven-week sampling period with habitat type as column variables and species as row variables. No supplementary row variables were used in either analysis. The analyses were conducted in Statistica 11.0.

Results and discussion

Species assemblage.—A total of seven acridid species were recorded during one year of sampling, including the less abundant *Orthochtha* sp. (Orthoptera: Acrididae) and *Z. elegans*. Five species, however, were of particular concern due to their high population densities (Fig. 2). The rank abundance plot indicates that *P. prosternalis* had the highest overall abundance over a one-year period, followed by *N. septemfasciata*. The extremely mobile nature of the latter species (Faure 1935) and particularly clumpy distribution (Rainey et al. 1957) meant that sampling might have underestimated their abundance in relation to *P. prosternalis*. The other species, *C. zuluensis*, *C. aeruginosa*, and *O. cyanea,* were more evenly distributed over the sampling areas and generally easier to catch during the drive-netting period of sampling. Acridid species always occurred as a species assemblage. It was never observed that only one species occurred in a particular area, although species densities varied.

Molecular identification.—None of the species' DNA matched the sequences previously loaded onto GenBank or the BOLD websites accurately. All five specimen sequences were submitted to BOLD systems, as well as Genbank. The Genbank accession numbers are as follows:

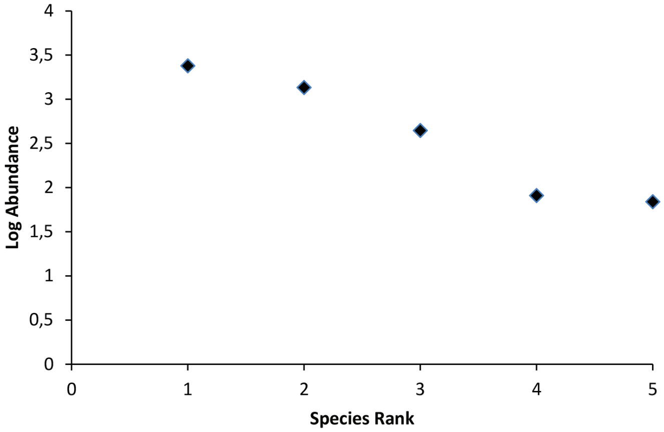

Fig. 2. Rank abundance plot of the five most prominent acridid species found in sugarcane in Zululand, South Africa (1: *Petamella prosternalis*; 2: *Nomadacris septemfasciata*; 3: *Cataloipus zuluensis*; 4: *Cyrtacanthacris aeruginosa*; 5: *Ornithacris cyanea*), based on population surveys carried out from May 2012 to May 2013 in four study sites.

Nomadacris septemfasciata: BankIt1690897 SASRI1001-13. COI-5P KJ130657
Cyrtacanthacris aeruginosa: Bank1t1690897 SASRI1002-13.COI-5P KJ130656
Petamella prosternalis: Bank1t1690897 SASRI1003-13. COI-5P KJ130659
Cataloipus zuluensis: Bank1t1690897 SASRI1004-13. COI-5P KJ130655
Ornithacris cyanea: Bank1t1690897 SASRI1005-13. COI-5P KJ130658

Population surveys and damage rating.—From the start of the surveys in May 2012, populations fluctuated, alternating between a high relative abundance of *P. prosternalis* in summer, and a high relative abundance of *N. septemfasciata* and *O. cyanea* in winter (Fig. 3).

At the beginning of August, only *N. septemfasciata* and *O. cyanea* individuals were still present as adults; this continued until October 2012, when the next generation of hoppers of all species emerged in a fairly synchronized manner. According to Bazelet (2011), who worked in natural veld sites in the Zululand region, *O. cyanea* is a univoltine species, which mates, lays eggs, and dies before the onset of cold, dry weather in winter. This is contrary to the findings of our study. Hoppers were present for roughly 3 months until about January 2012. During this period, *N. septemfasciata* and *P. prosternalis* were the dominant species while *C. zuluensis* made up roughly 20% of the hoppers collected. Hoppers of *C. aeruginosa* and *O. cyanea* were found in very low numbers. *Cyrtacanthacris aeruginosa* was further found to have an egg diapause, which substantiates the findings of Jago (1968).

During the period of May 2012 to May 2013, the damage-rating index fluctuated substantially, indicating that damage varies in relation to population density and possibly the season and growth stage of the sugarcane plant (Fig. 3). Damage was initially at 1.4 on the damage-rating index but started to increase as the season progressed into winter. Thereafter damage started to decrease to a level of 1, roughly at the same period of *P. prosternalis* numbers de-

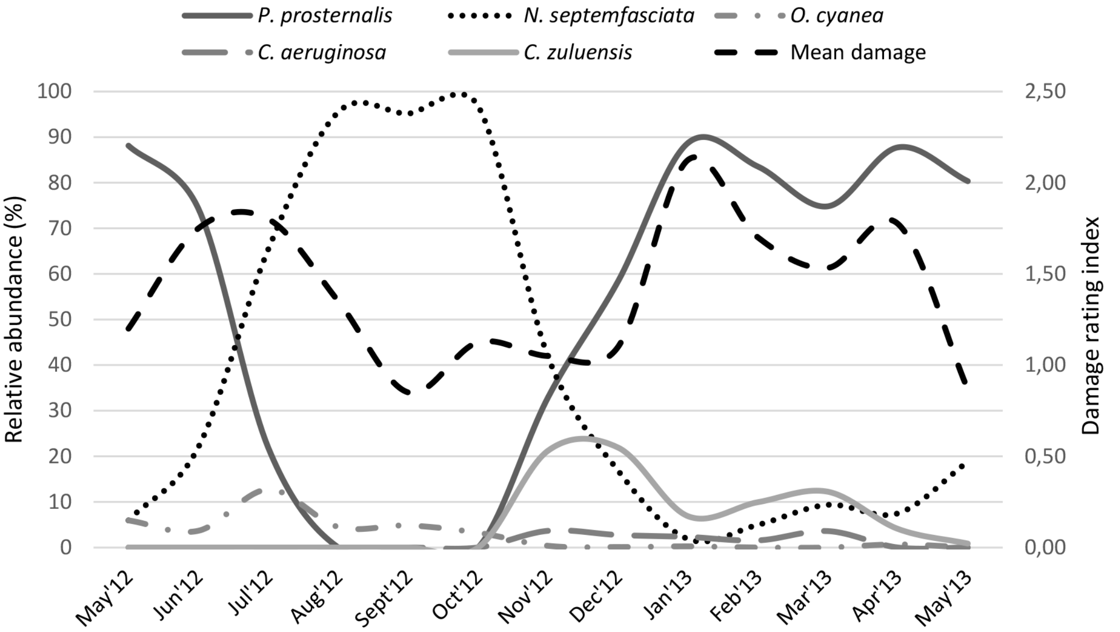

Fig. 3. Population survey showing the relative abundance of the five most prominent acridid species in sugarcane in relation to the damage rating index on the secondary y axis.

creasing. Damage remained fairly low and constant until mid-November, possibly due to the hopper populations. As they grew into 3rd and 4th instar, and therefore increased in body size, adults fed more, which would explain the increase in damage over this time (Fig. 3). The population dynamics of *N. septemfasciata* observed in our sugarcane study site was comparable with the findings of Lecoq et al. (2006, 2011) in Madagascar. Both of these studies defined three different geographical areas where *N. septemfasciata* populations migrated to and from as a result of seasonal climatic changes, and the term 'main rainy season breeding zone' was suggested.

The Empangeni area (Zululand region of KwaZulu-Natal, South Africa) would qualify as such a breeding zone, as high *N. septemfasciata* numbers were only found in this region of the province. In Madagascar, long range migrations of *N. septemfasciata* have been proven to occur (Lecoq et al. 2006) while in South Africa, this has not yet been shown. The likelihood of significant *N. septemfasciata* migrations occurring in the Zululand region, however, are slim given the fact that the current population surveys have shown that adults remain in the vicinity throughout the dry winter period. These findings contradict those of Faure (1935) that "South Africa does not serve as a permanent breeding ground of the *N. septemfasciata* in its solitary phase". Lecoq et al. (2011) found that during an eight-year study, the biological cycle of *N. septemfasciata* repeated with regularity, although the diapause cycles of all species in the current study generally coincide with the change in seasons and onset of summer rains – thus causing early researchers to presume rainfall was the main factor involved (see: Robertson 1958, Franc and Luong-Skovmand 2009). It has recently been found that the photoperiod is the factor that is responsible for initiation and cessation of diapause (Lecoq et al. 2011). This finding could possibly explain why initiation and cessation of diapause is earlier in South African *N. septemfasciata* populations compared to those in Madagascar.

Damage reached a peak at the end of January 2013, which was when grasshopper population density was the greatest as most individuals had undergone their final molt to become adults and the effects of natural mortality over time were small.

The damage rating index was significantly correlated with the fluctuations of *P. prosternalis* and *N. septemfasciata* (Table 3), indicating the close relationship between *P. prosternalis* population density and damage to sugarcane (Fig. 3, Table 3).

These results suggest that the combination of *P. prosternalis* and *N. septemfasciata* currently pose the greatest risk to South African sugarcane in terms of crop damage. A shortcoming of the damage rating index is that it does not take into account the growth rate of the plant being analyzed over time. Three of the four survey sites were dryland sugarcane farms; therefore, a decrease in rainfall over winter may slow down plant recovery after feeding and cause damage to be overestimated during winter months.

Seasonal life cycle.—Population surveys and personal observations by AB indicated that the five main species in sugarcane are all univoltine (completing one generation per year). All species had a diapause period although the life stage that entered into diapause differed between the species (Table 4). *Nomadacris septemfasciata* and *O. cyanea* overwintered as the adult stage. The immature adults entered a reproductive diapause at the onset of the dry season, only becoming reproductively active five or six months later

Table 3. Relationship between acridid species abundance and damage rating in four sugarcane study sites in Zululand, KwaZulu-Natal.

Species	Damage rating (gamma statistic)
P. prosternalis	0.429143*
N. septemfasciata	0.250408*
O. cyanea	0.111739
C. aeruginosa	-0.190004
C. zuluensis	0.152348

*indicates species with population densities that were significantly ($P<0.05$) correlated with observed damage estimates.

at the onset of the rainy season (October). *Petamella prosternalis*, *C. aeruginosa*, and *C. zuluensis* exhibited a different overwintering strategy whereby the adults mated and then the females laid their eggs and died before the onset of the dry season in April or May. The eggs then lay dormant in the soil for up to 7 months until rains began towards October (Table 4).

Species composition.—Figure 4 illustrates the mean abundance of six species found at the four sugarcane study sites and the two grassland study sites. Species abundance, diversity, and composition differed between the six study sites, with *N. septemfasciata* being the most abundant on GSA and Crystal Holdings. Very few *N. septemfasciata* individuals were recorded in grassland sites. *P. prosternalis* was most abundant on GSA and Jengro during this period while in grassland sites, very few individuals were recorded. *Orthochtha* species had higher abundance levels in the grassland sites compared to sugarcane. *Cataloipus zuluensis* was equally abundant in sugarcane as in grassland sites, acting as a generalist feeder. *Zonocerus elegans* was almost exclusively found in grassland sites indicating this habitat as being preferable. *Cyrtacanthacris aeruginosa* was recorded in low numbers everywhere except one of the grassland sites where high numbers were counted. Bazelet (2011) recorded no *Orthochtha* sp., one *C. aeruginosa*, and two *Z. elegans* individuals during her study in the Zululand region in semi-natural habitat.

Table 4. Simplified summary of the two diapause strategies observed within the grasshopper assemblage attacking South African sugarcane. Bold rows indicate southern hemisphere winter months.

Month	Egg diapause present	Reproductive diapause present
	P. prosternalis, *C. aeruginosa*, *C. zuluensis*	*N. septemfasciata*, *O. cyanea*
January	Hoppers	Hoppers
February	Hoppers	Hoppers
March	Mating/oviposition	Hoppers
April	Mating/oviposition	Reproductive diapause
May	Mating/oviposition	Reproductive diapause
June	**Egg diapause**	**Reproductive diapause**
July	**Egg diapause**	**Reproductive diapause**
August	**Egg diapause**	**Reproductive diapause**
September	Egg diapause	Reproductive diapause
October	Egg diapause	Mating/oviposition
November	Hoppers	Mating/oviposition/Hoppers
December	Hoppers	Mating/oviposition/Hoppers

Grassland sites were more similar in acridid assemblage structure, the species occurring there falling mostly to the right of the graph, while sugarcane sites were also more similar but with a different acridid assemblage structure, falling to the left of the graph (Fig. 5). *Zonocerus elegans*, *Orthochtha* sp., and *C. aeruginosa* were closely associated with grassland sites with dimension 1 accounting for 46.62% of the inertia. Dimension 2 (whilst only capturing 23.82% of inertia) indicated that *N. septemfasciata* is closely associated with sugarcane sites at a high order of magnitude, and, similarly, *P. prosternalis* shows a strong association with sugarcane sites but at a low order of magnitude. In a study by Bazelet (2011) in natural grasslands in the Zululand region, over two years, no *N. septemfasciata* and only 22 individuals of *P. prosternalis* were caught in her sites. This indicates that these two species prefer sugarcane to grasslands in this area as a habitat. Michelmore (1947) and Burnett (1951) found that hoppers and adults of *N. septemfasciata* in the Rukwa Valley, Tanzania, showed a marked preference for tall dense grass. Lea and Webb (1939) also found that *N. septemfasciata* hoppers, when disturbed in short grass, would shelter in tall clumps of grass. Generally, sugarcane gets much taller than surrounding natural grasslands, especially over winter in our study areas, which could explain why *N. septemfasciata* preferred tall sugarcane over shorter grassland areas.

Nomadacris septemfasciata are capable, over time, of covering distances of over 1000 miles or more (Rainey et al. 1957) but during the study period, all species including *N. septemfasciata* were confined to relatively small areas in Empangeni. Sugarcane, espe-

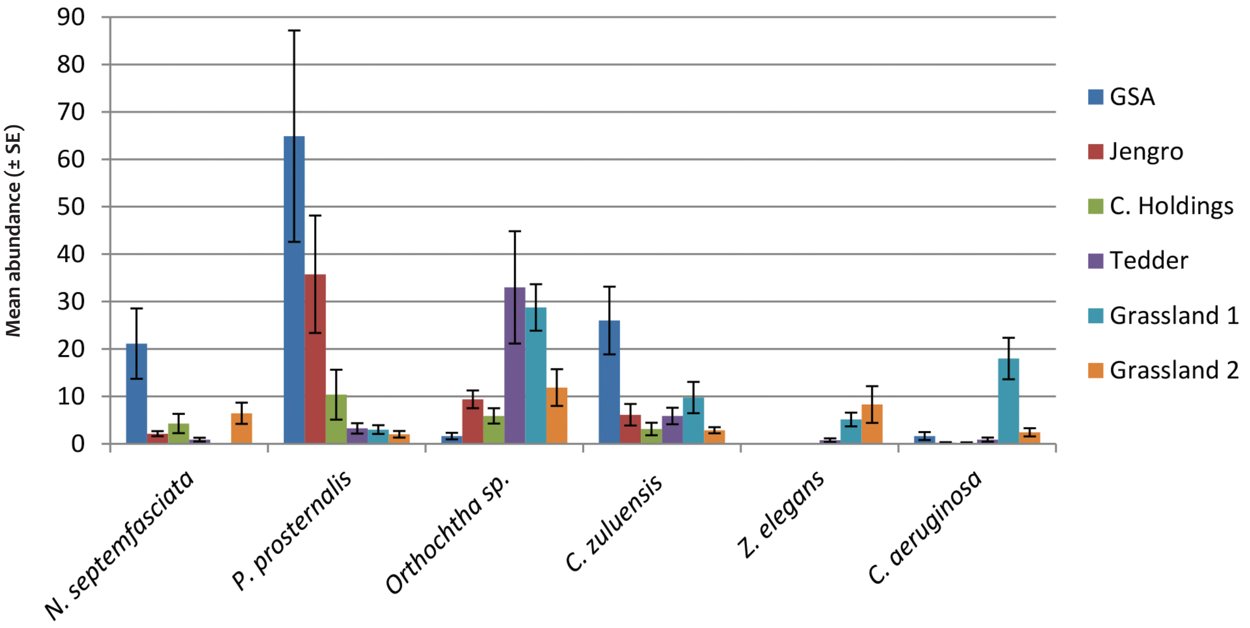

Fig. 4. Mean abundance (± SE) of six species of grasshoppers surveyed at the four sugarcane sites and the two grassland sites for the period 21 November 2012–19 February 2013.

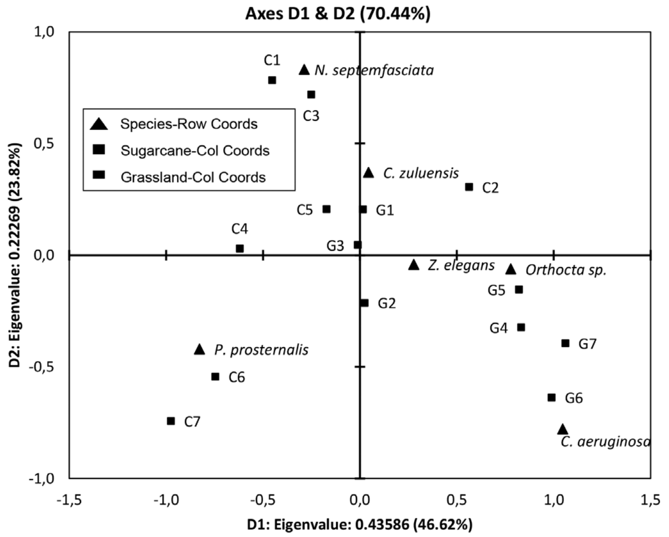

Fig. 5. Association between grasshopper species and habitat. Correspondence analysis showing the association between grasshopper species in relation to sugarcane and grassland survey sites sampled over a seven-week period from 21 November 2012–19 February 2013.

cially irrigated, may be the factor causing *N. septemfasciata* populations to remain quite sedentary in the study area, contrary to their mobile nature (Lea 1935). Grasshoppers will always remain pests of local importance, and currently it seems the locust *N. septemfasciata* could remain a pest of local importance. However, the potential for population upsurges of this species resulting in significant outbreaks should not be underestimated.

Conclusion

Species identification and their population dynamics are the first steps in developing an integrated pest management plan. Population surveys have shown that *P. prosternalis* is the most abundant species in sugarcane in the Zululand region, followed by *N. septemfasciata*. These two species should, therefore, be considered as the primary targets for IPM. The other three species—*C. zuluensis*, *C. aeruginosa*, and *O. cyanea*—are found at lower but appreciable numbers and therefore should not be ignored as their potential for population increase is not well known but certainly possible. All species studied are univoltine, which means that to correlate population fluctuations with weather variables as done in previous literature (see Chiconela et al. 2003), surveys will have to be completed over a longer period in order to determine the significant effect of climate on acridid populations. The findings further show that the distribution of species among farms and natural habitat areas is not uniform, some species being found at higher densities on certain farms or in certain habitats. These findings provide important information for managers and growers in that they enable the development of a more species-specific management plan.

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