THE IMPLEMENTATION OF A PUSH-PULL PROGRAMME FOR THE CONTROL OF *ELDANA SACCHARINA* (LEPIDOPTERA: PYRALIDAE) IN SUGARCANE IN THE COASTAL REGIONS OF KWAZULU-NATAL, SOUTH AFRICA.

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Abstract

Eldana saccharina, an indigenous lepidopteran stemborer, is considered the most damaging pest of sugarcane in South Africa. Researchers have advocated the use of an area-wide integrated pest management (AW-IPM) programme as a means of improving the control of this pest. A push-pull strategy was developed as a component of this AW-IPM approach. The push-pull strategy in sugarcane is a habitat management method of pest control that uses plants that are both repellent (*Melinis Minutiflora*) and attractive (*Cyperus dives*, *Cyperus papyrus* and *Bt*-maize) *to E. saccharina*. Previous research into push-pull has shown that this strategy is an effective tool for the control of *E. saccharina*. Push-pull has been implemented successfully in the Midlands North sugarcane growing region of KwaZulu-Natal (KZN), South Africa. Despite the proven efficacy of push-pull, very little push-pull research has been conducted in the coastal sugarcane growing regions of KZN, and adoption of this technology has been poor in these regions. Therefore, the aim of this research was to facilitate the implementation of push-pull for the management of *E. saccharina* in sugarcane in the coastal regions of KZN. This was done by focussing on on-farm field trials and farmer participatory research.

On-farm push-pull field trials were conducted on five model farms in the North and South Coast sugarcane growing regions of KZN. High levels of *E. saccharina* were recorded during this study. The push-pull treatment sites showed a significant reduction of *E. saccharina* damage on four of the five farms used in the study. Mean percentage of stalks damaged decreased by up to 50 % in the presence of the repellent grass species, *M. minutiflora*. The number of *E. saccharina* found per 100 stalks also decreased significantly at these farms. The farm which did not show a significant reduction in *E. saccharina* populations or damage had low numbers of this pest in the sugarcane throughout the experiment. This demonstrates that push-pull is more effective in areas that have high levels of *E. saccharina*. Stem borer surveys in wetlands on sugarcane farms revealed that high numbers of *E. saccharina* were found within the pull plants, *C. papyrus* and *C. dives*, in comparison to the push-pull sites. This verifies that the pull plants do work efficiently to attract *E. saccharina* away from sugarcane. Additionally, eight parasitoids emerged from *E. saccharina* larvae collected in wetland sedges. The beneficial roles that push-pull plants play in attracting and maintaining natural enemies in the agroecosystem are discussed, and these findings further demonstrate the important ecosystem, and pest management services that wetlands provide on sugarcane farms. The success of the push-pull trials in this study show that this technology can be an effective tool for controlling E. saccharina in the coastal sugarcane growing regions. The timing of the planting of push-pull plants was shown to play a role in the efficacy of this technology. The study also confirmed that push-pull should be used as a component of AW-IPM in conjunction with good crop management practices.

Surveys were undertaken to determine large-scale sugarcane growers' (LSGs) knowledge and perceptions of *E. saccharina* and other pests. Research regarding the farmers' perceptions of push-pull was also conducted to better understand the drivers and barriers to adoption of push-pull, and other new technologies. The surveys found that large-scale farmers in the coastal regions suffer from high infestations of *E. saccharina*. As such there is scope for the introduction of new pest management practices such as push-pull in this area. Farmers also demonstrated a good basic knowledge of *E. saccharina* and IPM. However, LSGs had a poor understanding of push-pull and how it works, as well as the plants that make up the push-pull system that is being implemented against *E. saccharina* in South Africa. A dearth in practical knowledge regarding the implementation of push-pull was seen as a major barrier to the adoption of this strategy, as was financial instability, farmer attitudes and poor institutional support. Farmers recommended collaboration amongst stakeholders, improved education, proof of the efficacy of push-pull and incentives as tools to improve the implementation of this strategy in the coastal sugarcane growing regions of KZN. Farmers preferred direct contact with extension personnel and experiential learning opportunities when acquiring information about push-pull and other new pest management practices. If opportunities for push-pull education are increased through direct contact with extension personnel, and through on-farm demonstrations, and if inputs are provided in the form of push-pull plants, it is likely that push-pull will succeed amongst coastal LSGs, especially since farmers had an overall positive attitude towards the technology.

Surveys amongst small-scale sugarcane growers (SSGs) showed that sugarcane is important in the lives of these farmers. The SSGs perceive pests to be a major constraint to their farming systems, and they identified *E. saccharina* as a major pest of sugarcane. The farmers also demonstrated good knowledge of sugarcane pests and vegetable pests. However, SSGs lacked knowledge regarding pest management practices and beneficial insects. Extension and advisory services should to continue concentrating on pest management practices to educate SSGs on the variety and application of pest control strategies. SSGs were found to employ complex, diverse and integrated agricultural systems that are well-suited to the implementation of IPM technologies such as push-pull. Since insect pests act were found to be a major constraint to SSG sugarcane production, push-pull was deemed a feasible pest management strategy for coastal farmers and its implementation by SSGs should be further explored. SSGs in this study were also concerned about vegetable pests, therefore if push-pull can be adapted to help protect additional crops, adoption of this technology by small-scale growers will improve.

Keywords: *Eldana saccharina*, sugarcane, pest management, habitat management, IPM, push-pull, farmer perceptions, agriculture, agroecosystem, farmer participation, wetlands

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Chapter 1

General Introduction

1.1. Introduction

Sugarcane (*Saccharum officinarum* L. (Poales: Poaceae)) is an economically important crop in South Africa and plays a significant role in the livelihoods of thousands of people (FAO 2010, BFAP 2013). However, the farming of sugarcane is severely limited in South Africa due to various geographical, biological, social and economic factors (Nieuwoudt and Groenewald 2003, BFAP 2013). To ensure that the industry continues to be successful, every effort should be made to maximise production and improve yields (Nieuwoudt and Groenewald 2003). The most damaging pest on sugarcane, *Eldana saccharina* Walker (Lepidoptera: Pyralidae) is regarded as a major constraint to the production of the crop in South Africa (Keeping 2006). This indigenous stem borer causes significant losses in sugarcane yields throughout the industry, particularly along the coastal belt of KwaZulu-Natal (Goebel and Way 2003, Assefa et al. 2008). Much research has focussed on attempts to control *E. saccharina* populations on sugarcane farms (Keeping 2006). Despite this, conventional methods have failed to provide adequate solutions to the *E. saccharina* problem (Rutherford and Conlong 2010), and an integrated pest management (IPM) programme was developed (Webster et al. 2005).

IPM is based on the knowledge of a pest's biology, and focuses on the use of multiple pest control methods, in a holistic and integrated way to target vulnerable areas of the pest's life cycle (Kogan 1998, Ehler 2006). IPM incorporates decision making processes based on knowledge of the pest and its ecology, old agricultural practices and new technologies to control pest outbreaks, whilst also reducing the use of ecologically damaging pesticides (Kogan 1998, Rutherford and Conlong 2010). A new technology that was developed for use within an IPM framework is stimulo-deterrent diversion (SDD) or push-pull technology (PPT). PPT is a form of habitat management that seeks to manipulate pest populations using components of the agroecosystem as tools (Kasl 2004). Plants, emitting specific semio-chemicals (chemical signals), are strategically placed within and around a farm to repel (push) and attract (pull) pests away from the target crop (Kasl 2004). PPT is also regarded as a conservation biological control method, which simultaneously deters pests and re-introduces biodiversity and natural enemies into the agroecosystem (Gurr et al. 2004, Cook et al. 2007). These natural enemies can then help suppress any pests in the system (Cook et al. 2007).

After it proved successful against maize stem borers in East Africa (Khan et al. 2014), a push-pull programme was developed for use in sugarcane to control and reduce *E. saccharina* populations (Kasl 2004, Barker 2008, Cockburn 2013). *Eldana saccharina* (also referred to by its common name, eldana) is an indigenous insect and as such, has a complex of natural host plants that can be used to attract the pest away from sugarcane (Kasl 2004). *Cyperus papyrus* L., *Cyperus dives* L. (both Poales: Cyperaceae) and *Zea mays* L. (Poales: Poaceae) were chosen as pull plants for *E. saccharina*, whilst *Melinis minutiflora* P. Beauv (Poales: Poaceae) was selected as a push plant (Conlong et al. 2007). Sugarcane which was planted alongside these plants showed significantly reduced damage by *E. saccharina*, thus demonstrating the ability of this technology to control the pest (Barker et al. 2006, Barker 2008, Cockburn 2013). However, despite the proven success of PPT, its adoption by farmers has been poor, especially along the coastal belt of KZN. It has been predicted that this may be due to the fact that most of the research on PPT in sugarcane has been conducted in the Midlands North region of KZN, where *E. saccharina* numbers are typically low (Webster et al. 2005, Barker 2008, Cockburn 2013). However, without further research the reasons behind the lack push-pull implementation along the coast cannot be successfully determined.

Adoption of new IPM techniques requires a shift in paradigms, with participation, farmer input, interdisciplinary research, interaction and learning being identified as the keys to achieving successful adoption (Leeuwis 2004). Khan et al. (2008a) and Cockburn et al. (2013) found that farmers' backgrounds and perceptions of pests and pest control can inform us about the mechanisms of adoption with regards to PPT. This information can be used to tailor PPT to suite the farmers' needs, thereby improving implementation and ultimately production and farmer livelihoods (Cockburn et al. 2012, Cockburn 2013, Cockburn et al. 2014). As such, the current project seeks build on the work of Cockburn 2013 in the Midlands North region, to gain a better understanding of the constraints and perceptions of both small-scale growers and large-scale growers on the north and south coasts of KZN. The study aims to assess the ability of PPT to reduce *E. saccharina* populations in the area, and to provide famers with more information about the benefits of these practices, so that they can improve their own decision-making processes. Hopefully this can help to improve implementation of PPT and IPM practices so that *E. saccharina* levels can be better managed and reduced.

1.2. Sugarcane

1.2.1. A basic description

Sugar is primarily made from the juices of a rigid, upright grass, *S. officinarum*, better known as sugarcane (Stevenson 1965). It is a hybrid, derived from 2 wild ancestors (Overholt et al. 2003), *Saccharum robustum* L. and *Saccharum spontaneum* L. (Stevenson 1965). The latter was originally from Melanesia, whilst *S. spontaneum* was first found in parts of East Africa and Southern Asia (Overholt et al. 2003). Sugarcane is said to be the largest commercially grown crop in the world (Overholt et al. 2003). This is due to the fact that it can be widely used for the production of not only sugar, but also molasses, alcohol, syrups, ethanol and biofuel (Overholt et al. 2003; FAO 2010).

Sugarcane is a sub-tropical species, and performs well in parts of North and South America, Africa, Southern Asia and Australia, with Brazil and India being the principal producers of the crop (Osborn 1964, FAO 2010). Sugarcane was first introduced into South Africa in the mid 1800's (Atkinson et al. 1981). Unfortunately, production in South Africa is hindered by dry summer climates, winter rainfall, low winter temperatures and frost in many areas of the country (Lewis, 1990, DAFF 2012). However, good conditions for sugarcane growth do exist in certain areas of Mpumalanga, the Eastern Cape and KwaZulu-Natal (Lewis 1990). KwaZulu-Natal is the biggest producer of sugarcane in the country, with production being limited only by the July minimum temperature isotherm of 5°C (Osborn 1964, DAFF 2012).

1.2.2. Sugarcane in South Africa

South Africa is the 11th largest producer of sugar amongst 121 sugarcane growing countries (FAO 2010). As such the sugar industry is an important contributor to the national economy, generating up to R6 billion in annual direct incomes (BFAP 2013). The industry also provides significant employment opportunities, particularly in rural areas (BFAP 2013). It is estimated that direct and indirect employment through the sugar industry provides approximately 350 000 jobs in KwaZulu-Natal, Mpumalanga and the Eastern Cape, where sugarcane is primarily grown (DAFF 2012). This means that, in total, over one million people in South Africa are dependent on the production of sugarcane (BFAP 2013).

Despite the economic importance of sugar production, area under sugarcane in South Africa has declined by an estimated 14%, from 431 800 ha in 2001 to 371 000 ha in 2012 (BFAP 2013). Rising fuel costs, urbanization, lack of investment due to land claims, unsuccessful land reform projects, high fertilizer prices and seasonal droughts have all been identified as contributing factors towards this declining trend (Nieuwoudt and Groenewald 2003, BFAP 2013). Because of this, much emphasis is being placed on maximising the amount of sugar produced by both large (LSG's) and small-scale growers (SSG's) (Nieuwoudt and Groenewald 2003).

There are many constraints to sugarcane production in South Africa, amongst these are weeds, insect pests, nematodes and diseases. One of the means of improving sugarcane yields is through the effective control and management of sugarcane pest populations (Nieuwoudt and Groenewald 2003).

As the most economically damaging pest on sugarcane in South Africa, much research has been focused on controlling *Eldana saccharina* in an attempt to improve sugarcane returns (Keeping 2006).

1.3. Eldana saccharina

1.3.1. History of the pest in South Africa

Eldana saccharina, more commonly known as the as the African sugarcane stem borer, or eldana, was first recorded as an indigenous pest on sugarcane in South Africa in 1939, during an outbreak in the Umfolozi area in Northern Natal (Dick 1945). The outbreak died out in 1953 and the pest went largely unnoticed for several decades, despite it being simultaneously recognised as a major problem in West and East Africa, where it was known to attack cereal crops and sugarcane (Girling 1971, Carnegie 1974). Interest in the moth was only generated again in the 1970's when *E. saccharina* was found infesting crops in KwaZulu-Natal (Atkinson et al. 1981). Intensive research on the moth only began in the mid 1980's when its status as a highly problematic pest on sugarcane was confirmed (Conlong 1997). In recent years, *E. saccharina* infestations can be found throughout the South African sugarcane growing area and causes major crop losses if left uncontrolled (Goebel and Way 2003, Rutherford 2015).

1.3.2. Biology of the Pest

Eldana saccharina is an indigenous African pest (Dick 1945, Conlong 1994). It is a stem boring moth, whose native hosts are sedges, mostly *Cyperus* species, and numerous other large grasses found in wetland habitats (Atkinson 1980). Indigenous hosts in Southern Africa include plants in the families Graminae, Cyperaceae, Poaceae and Juncaceae (Conlong 2001). It is hypothesised that the pest moved into sugarcane as a result of the disturbance and destruction of its natural wetland habitats as a result of agriculture, changing watercourses and afforestation (Osborn 1964, Atkinson et al. 1981, Rutherford 2015). In addition to this, *E. saccharina* has been able to thrive as a pest in sugarcane because its movement into the crop has provided a means of escaping a complex of natural enemies that exist in its wild indigenous hosts (Conlong 1994, Conlong 1997).

Eldana saccharina adults are light brown, with a wing span of approximately 30 mm in males and 39 mm in females (Carnegie 1974). The hind wings of the species are white and are typically folded across the abdomen when the moths are at rest (Maes 1998). Moths emerge shortly after sunset to mate (Carnegie 1974). Once mated, the females begin to oviposit after approximately 24 hours (Carnegie 1974, Walton 2011). Females live for 6-15 days and are able to fly 200 m or more before ovipositing, meaning that they can easily disperse into neighbouring fields (Carnegie 1974, Maes 1998). Despite their longevity female moths lay the majority of their eggs 2-5 days after they have eclosed (Walton

2011), and each individual is able to lay, on average, 400-600 eggs in batches of between 20 and 50 (Shanower et al. 1993, Maes 1998). Eggs are generally found on the inner side of leaf sheaths and in the area between the stem and the soil, but they may also be laid on plant residue material (Carnegie 1981, Sampson and Kumar 1985). The eggs hatch 8 to 10 days after oviposition (Carnegie 1974).

Neonate larvae do not enter the cane stem immediately, but feed initially on organic matter on cane leaves and under leaf sheaths (Carnegie 1974). After a variable period, the larva is sufficiently robust to penetrate the stalk by boring through buds, nodes or cracks in the rind, remaining there as a borer in the sugarcane stem until the larva is ready to pupate (Girling, 1971, Carnegie 1974). The larval period consists of six instars and varies from about 20 days in summer to 60 days in winter (Carnegie 1974). Larvae feed on the internal tissues of the sugarcane stalk, creating tunnels within the stem, whilst simultaneously pushing frass to the exterior through moth exit holes, which are cut by the larvae prior to pupation (Girling 1971, Carnegie 1974). Larvae are light brown to dark grey, but can be easily identified by their tendency to move vigorously (both backwards and forwards) when disturbed (Carnegie 1974, Maes 1998). Mature larvae spin a protective cocoon in which to pupate, after which the mature moth emerges in 10 days (Carnegie 1974). Pupae can be found very close to (within 5 cm), or just outside their exit holes (Sampson and Kumar 1985).

Once the stalk has been split open, *E. saccharina* damage can be easily recognised by the extensive mining holes that it creates and by the red discoloration of the damaged plant tissue (Schulthess et al. 2002, Way and Goebel 2003). This red discolouration is caused by a fungus (*Fusarium* species), which infects the sugarcane tissue surrounding the boring sites (Ako et al. 2003, McFarlane et al. 2009). This fungus is typically beneficial to the insect and can exacerbate reductions in sugarcane quality (McFarlane et al. 2009). During high *E. saccharina* infestations the sugarcane stick can become thin and brittle, resulting in severe crop loss and low sucrose yields (Carnegie 1974, Way and Goebel 2003).

1.3.3. Economic impacts of the pest

It is estimated that *E. saccharina* reduces sugarcane yields by 0.1 % for every 1 % of stalks bored, or alternatively, 1 % of useable sugar is lost for every 1 % of internodes bored (Smaill and Carnegie 1979, King 1989). Since *E. saccharina* prefers older, stressed sugarcane, growers can offset their losses by managing their soil and water and by harvesting cane soon after maturation at 12 months (Leslie 1994). However, sucrose levels in sugarcane improve as the cane ages and it should ideally be harvested at 18-24 months (Rostron 1972). Sugarcane that is aged and kept for harvest in the following season is called 'carry-over' sugarcane. Differences do exist between various varieties of sugarcane, as well as sugarcane planted during different times in the year (McCulloch 1989). However, Rostron (1972) showed that the older the crop is at harvest, the higher the concentration of estimated recoverable sugar there is in the cane. Therefore, early harvesting results in economic losses and is not an ideal method for managing *E. saccharina* populations (McCulloch 1989, Rutherford 2015).

Like all successful industries, sugarcane farming relies on a trade-off between financial costs and benefits. The benefits (output) of sugarcane production need to out-weigh the costs (inputs) of farming practices, and pest control, in order for the grower to turn a profit (Stern et al. 1959). Based on the above figures, pest populations must be carefully monitored to ensure that they do not exceed the economic threshold of approximately 10-13 E/100 (10 *E. saccharina* larvae per 100 stalks), this is the lowest population of the pest that will cause economic loss (Stern et al. 1959, Leslie 2009). Goebel et al. (2005) calculated that the economic injury level (EIL) for 'carry over' cane is 7 % SLR (stalk length red). This is directly related to the number of nodes in the stalk that are damaged and is equivalent to yield (sucrose) loss (Goebel et al. 2005, Leslie 2009). This figure can be equated to 54 % SD (stalk damage), which is the percentage of stalks that show evidence of damage by *E. saccharina* (Goebel et al. 2005). At damage levels above these, the EIL has been surpassed and economic viability will be seriously affected (Stern et al. 1959, Barker 2008). At this point, the economic viability of the sugarcane will continue to decline unless corrective measures are employed (Stern et al. 1959, Barker 2008). Action needs to be taken to control the pest or the sugarcane needs to be cut early to avoid further loss (Stern et al. 1959, Leslie 1994).

1.4. Controlling *Eldana saccharina*

Previous research into the control of *E. saccharina* has focussed on established methods such as chemical, mechanical, cultural and biological control (Barker 2008). The development of resistant sugarcane varieties also plays a major role in the suppression of *E. saccharina* populations, and research into new and improved resistant varieties is an ongoing process (Keeping 2006).

1.4.1. Chemical Control

Currently, the only chemical pesticide registered for the control of *E. saccharina* in South Africa is alpha -cypermethrin (Fastac® SC) (Leslie 2009). Alpha-cypermethrin is a synthetic pyrethroid that is dissolved and applied in liquid form (Leslie 2003). It is recommended that farmers mix 200 ml of the formulation in 30 L of water for every hectare of sugarcane that is to be sprayed. The chemical is applied aerially or alternatively it can be sprayed by hand using a knapsack. Despite being effective against *E. saccharina,* alpha-cypermethrin requires multiple applications to produce significant reductions in pest populations (Leslie 2003). Sugarcane should be sprayed 3-8 times with Fastac® to ensure a decrease in *E. saccharina* damage (Leslie 2003). As such, this chemical is usually advised for use on 'carry over' sugarcane (Leslie 2009). Unfortunately, over reliance on a single synthetic insecticide is often associated with increased levels of pesticide resistance amongst insect pests (Brattsten et al. 1986). To negate such problems, other chemicals have been, and are currently being assessed to test their effectiveness against *E. saccharina* (Leslie and Moodley 2015). New chemicals, namely; indoxacarb, chlorantraniliprole and triflumuron, have all shown promise as alternative pesticides for use against *E. saccharina* (Leslie and Moodley 2015).

1.4.2. Cultural and mechanical control

Cultural control and mechanical pest control methods such as crop rotation, tillage practices, barrier and trap crops, harvesting schedules and other forms of crop and land manipulation have been used for centuries by farmers (Van den Berg et al. 1998, Gurr et al. 2004). Cultural control methods are still the preferable means of pest control for the majority of resource deficient farmers in Africa, who cannot afford costly pesticides (Abate et al. 2000, Kfir et al. 2002). Cultural and mechanical methods of pest control are prevalent in sugarcane farming and, although such methods are regularly practiced, they are continuously increasing in popularity due to the greater emphasis placed on the environmental issues associated with chemical sprays (Abate et al. 2000).

Practices, such as the harvesting of newly matured or young sugarcane, as discussed previously, are commonly used by growers to prevent high levels of infestation (Leslie 1994). Pre-harvest burning can also help to destroy *E. saccharina* eggs and young larvae that are found on the dried outer leaves of sugarcane (Carnegie 1974, Carnegie 1981). Cutters that remove stalks below ground level diminish the amount of material that larvae can reside in. This practice has the added benefit of reducing potential oviposition sites and thus helps to prevent re-infestation (Carnegie 1974). Piling soil over cut stools also decreases the survivability of any individuals that persist (Carnegie 1974). Furthermore, good soil management can help to reduce *E. saccharina* levels by ensuring that the crops are healthy and that they have the resources they require for optimum growth (Carnegie 1981). This is particularly important because *E. saccharina* favours stressed plants and will readily invade sugarcane which has been adversely affected by either low rainfall, waterlogging or poor soil conditions (Webster et al. 2009).

Methods, such as mulching, and increasing soil organic matter, as well as reducing compaction tillage have all been shown to support the increase of natural populations of soil organisms, including entomopathogenic fungi and nematodes, and predaceous mammals and arthropods, which are detrimental to insect pests and can contribute to the suppression of pest populations, with relatively little input from the farmer (Keller and Zimmerman 1989, Landis et al. 2000, Rutherford and Conlong 2010). Green manuring is another tool that can be used by farmers to improve soil health (Cherr et al. 2006). Green manures are plants that can be grown together with a cash crop or as cover crops during replant and fallow periods (Schumann et al. 2000). These plants are typically reincorporated into the soil while they are still green and are then left to decompose (Schumann et al. 2000). This improves soil organic matter, nutrient cycling, water infiltration and retention and reduces soil erosion and compaction (Cherr et al. 2006). If chosen and planted correctly, green manures can reduce pests, weeds and diseases and provide an important break in pest and disease cycles (Rhodes et al. 2012). Legumes are particularly useful as cover crops and green manures because they are also able to produce biologically fixed nitrogen, thereby making it more available for use by the cash crop (Rhodes et al. 2012). In sugarcane, fields previously planted with green manures consistently out-perform fields that have been replanted without a fallow period, as well as fields that have been subjected to a bare fallow or a weed-only fallow period (Garside and Bell 2011, Rhodes et al. 2012, Rutherford 2015).

The mechanical and cultural control methods mentioned above are beneficial to the environment and the farmer because they are able to reduce the necessity of both fertilizers and insecticides (Landis et al. 2000). This can help to curb input costs and prevent unnecessary environmental impacts through leaching and non-target effects (Cherr et al. 2006). This is particularly important because the addition of fertilisers to the soil may increases the risk of *E. saccharina* infestation by improving nutrient availability (Van Antwerpen et al. 2011). However, Rhodes et al. (2013) questioned the economic benefits of curtailing Nitrogen applications in an effort to decrease *E. saccharina* damage. They showed that the gains from such actions are offset by the reductions in yield that result from poor soil nutrition (Rhodes et al. 2013). Their results indicated that farmers are better off using the fertilizer rates that are recommended for their soils, regardless of *E. saccharina* risk, and that further additions of silicon and potassium to their soils could help to protect against E. saccharina infestation (Rhodes et al. 2013).

1.4.3. Biological control

As an indigenous pest, *E. saccharina* already has a wide range of natural enemies in its indigenous host plants, making the implementation of classical bio-control problematic (Conlong 1990). As a co-evolved species, *E. saccharina* has already developed a number of coping mechanisms in response to its natural enemies (Conlong 1990). Since 1992, surveys for indigenous parasitoids of *E. saccharina* in a variety of wild hosts and African habitats have resulted in 30 species of larval parasitoids being discovered in eight countries (Conlong 2000). Several of these have failed to parasitize *E. saccharina* under laboratory and field conditions in South Africa (Conlong 2000). This may be due to incompatibility caused by genetic differentiation between the Western, Eastern and Southern African populations of *E. saccharina* (King et al. 2002, Assefa et al. 2006). Furthermore, of the larval parasitoids that have been collected, only 30 % can be identified to species level (Conlong 2000). This has resulted in a lack of knowledge regarding the biology, ecology and life histories of these parasitoids, making them difficult to rear under laboratory conditions. Parasitized *E. saccharina* larvae that are collected in the field often yield only a one or two parasitoids of each species (Conlong 2000). These are not enough individuals to start a colony of laboratory bred parasitoids (Conlong 2000). It is difficult to identify potential *E. saccharina* control agents from wild populations of natural enemies if individuals die before they can be successfully mated (Conlong 2000). Conlong (1997) stated that the three-imported egg and seven imported larval biocontrol parasitoids, which could be reared in the laboratory, had constraints such as parasitizing ability, different host habitat, differing host behaviours in different habitats and initial host identification difficulties to overcome. Sugarcane also lacks the necessary semio-chemicals that attract parasitoids to damaged plants (Conlong and Kasl 2001). This explains why parasitoids that are commonly found parasitizing *E. saccharina* in its wild hosts, are not readily found on the pest in sugarcane (Conlong and Kasl 2001).

A few indigenous parasitoids are able to suppress *E. saccharina* populations in its indigenous habitat, including two native biocontrol agents, *Goniozus indicus* Ashmead (Hymenoptera: Bethylidae), and *Schembria eldana* Barraclough (Diptera: Tachinidae) (Barraclough 1991, Conlong 1997). These species are both larval parasitoids (Barraclough 1991). A new association biocontrol agent, *Xanthopimpla stemmator* Thunberg. (Hymenoptera: Ichneumonidae) has also shown good results against *E. saccharina* under laboratory conditions (Conlong 1994). New association biological control agents are introduced natural enemies that are not normally associated with the target pest, either because they are not found in the pest's native area, or because it is associated with a related pest species (Hokkanen and Pimentel 1989, Waage and Greathead 1988). *Xanthopimpla stemmator* is an Asian species that was imported from Sri Lanka to Mauritius to control an exotic sugarcane pest, *Chilo sacchariphagus* Bojer (Lepidoptera: Crambidae), also from south east Asia (Jepson 1939, Conlong and Goebel 2002). It was subsequently imported to South Africa as a potential control agent for *E. saccharina*, however it has not proven successful in the field (Conlong 1994). Despite low incidences of parasitism of *E. saccharina* in sugarcane, both of the afore mentioned indigenous parasitoid species, *G. indicus* and *S. eldana*, are being reared in the lab and released in stands of wetland sedges, where they are able to attack and control wild populations of *E. saccharina* (Conlong 1994, Conlong 1997). Research suggests that different biotypes of *E. saccharina* exist in the Western, Eastern and Southern regions of Africa (King et al. 2002, Assefa et al. 2006). Each biotype of *E. saccharina* has its own complex of natural enemies keeping the pest in check in its indigenous host plants (Assefa et al. 2006). Further research into the different types of parasitoids found in each region, and further collections of natural enemies could help scientists to better identify and understand the life-cycle of these parasitoids, so that can be reared and released against *E. saccharina* (Conlong 2000, Assefa et al.

2006). Perhaps this may lead to the discovery of biocontrol agents that may prove to be more effective against this pest in sugarcane (Conlong 2000).

1.4.4. Host plant resistance

Insect resistance in plants is the result of many complex and variable defence strategies that act against both herbivores and disease-causing pathogens (Rasmann and Agrawal 2009). Such mechanisms include physical barriers and the production of secondary metabolites and proteins, which can be toxic, anti-nutritive, repellent or aid in the recruitment of natural enemies (Gatehouse 2002, Rasmann and Agrawal 2009). The various plant defence mechanisms can work in isolation or concurrently to limit the damage caused by herbivorous attacks (Rutherford and Conlong 2010). They can be expressed constitutively, or they can be induced after feeding has commenced (Dent 2000). Plants guard against insect herbivores through direct or indirect defence mechanisms (Gatehouse 2002). Direct defences are plant defences that directly affect the herbivores biology, survival rate, reproductive success or host-plant preference (War et al. 2102). Indirect plant defences act against herbivores by attracting the natural enemies of the herbivore to the immediate environment using chemical cues and/or by producing food and housing structures (War et al. 2012).

Direct resistance of sugarcane to *E. saccharina* has been an area of intensive research (Keeping 2006). The development of resistant varieties has been a major tool in the combat against *E. saccharina* and several hardy strains are now in existence (Keeping 2006).

Direct host plant resistance can be broken down into three main categories of defence: non-preference (also referred to as antixenosis), antibiosis and tolerance (Painter 1968). Tolerance, whereby plants are able to offset the damage done by pests, remains relatively under investigated in sugarcane (Keeping and Rutherford 2004), therefore only antixenosis and antibiosis are discussed here. Plants, that employ antixenotic defences, affect the way that pests perceive the desirability of the host plant, thereby they are able to prevent insect feeding in the first instance (Dent 2000). These plants essentially effect of the behaviour of a pest (Dent 2000). They deter insect herbivores by producing repellent stimuli (unattractive colours, odours and physical textures, such as trichomes) or by failing to provide pest attracting stimuli (Smith et al. 2006). Unfortunately, ovipositional antixenosis (prevention of oviposition through host-plant resistance) has been shown to play an unimportant role in the *E. saccharina*-sugarcane interaction. However, researchers have been able manipulate sugarcane varieties, via breeding techniques, to express improved larval antixenotic properties (Keeping and Meyer 2002, Keeping and Rutherford 2004). Antixenosis is displayed in several varieties (N8, N12 and N21), and these can prevent feeding and development of *E. saccharina* larvae (Keeping and Rutherford 2004). These varieties offer resistance by way of physical structures, such as trichomes (plant hairs) or waxy cuticles (Keeping and Meyer 2002). The addition of silicon in soils, in the form of calcium silicate, can also improve antixenotic properties in sugarcane (Kvedaras et al. 2006). The silicon is incorporated into sugarcane plants and this, alongside lignin and fibre, can improve rind hardness (Keeping et al. 2009). The increased mechanical hindrance can help to reduce stalk penetration (Keeping et al. 2009).

Although antixenosis in sugarcane is an important method of defence against *E. saccharina*, antibiosis also plays a major role, especially against early instar larvae (Keeping and Rutherford 2004). Antibiosis is a form of plant defence that affects the biology of a pest, including its' development, feeding ability, reproduction and survival (Dent 2000). The antixenotic properties of sugarcane, as mentioned above, not only affect plant preference, but may also act as antibiotic against *E. saccharina* (Keeping and Rutherford 2004). This is because antixenotic properties increase larval mobility outside the sugarcane stalk due to delays in stalk penetration and increased host searching time. The resultant increase in larval exposure is likely to increase mortality by predation (for example by ants) and desiccation (Keeping and Rutherford 2004). Plant 'toughness' also improves early stage larval antibiosis in sugarcane (Keeping and Rutherford 2004). Increased rind hardness, fibre content, epicuticular wax and silicon accumulation adversely affect feeding, digestion, larval weight gain and the ability to chew in *E. saccharina* larvae (Kvedaras et al. 2006, Keeping et al. 2009). Whilst rind hardness and stalk fibre have been positively correlated with pest resistance in sugarcane, it is unfortunate that these characteristics are also closely associated with low sucrose content and both have negative effects on the milling process (Mahlanza et al. 2014). As such they are not desirable as selection traits for resistance against the stem borer (Keeping and Rutherford 2004, Mahlanza et al. 2014). There are some resistant varieties of sugarcane (N29, N39, N41) that have a moderate fibre content and are relatively high in recoverable sucrose (Keeping and Rutherford 2004). Such varieties demonstrate that plant 'toughness' is not the only factor which promotes resistance, and that plant chemistry and physiological reaction to damage play an equally important role (Keeping and Rutherford 2004). Chemical defences form a complex network of pathways and signals that can react specifically to different attacks on the host plant. These chemicals can be toxic and anti-nutritive to herbivores and are ultimately detrimental to their development on the plant. Research into chemical defence mechanisms can help us to learn more about plant defence, so that better resistant varieties can be developed (Rutherford 2014). However, there is a lack of literature regarding such antibiotic mechanisms in sugarcane (Rutherford 2015). Although scientists can infer some knowledge about the chemistry of such defences from similar grasses within the Poaceae family, understanding these mechanisms and how they work within sugarcane is invaluable if these chemicals are to be synthesized or induced in new varieties to promote resistance against *E. saccharina* (Rutherford 2015).

Upon herbivorous attack, many plant species emit complex volatiles, called herbivore-induced plant volatiles (HIPVs) or SOS volatiles, into the air from their vegetative tissues (Rutherford 2015). These plant volatiles are derived from complex biochemical processes and include fatty-acid derived products, such as jasmonic acid and green leaf volatiles (GLV), like hexenal and monoterpenes (Gurr and Kvedaras 2010, Conlong and Rutherford 2010). They serve as signals to not only repel pests, but to also attract predators and parasitoids of attacking herbivores, and to elicit similar responses in nearby plants (Khan et al. 2008b, Rutherford and Conlong 2010). This is referred to as indirect host-plant defence. Unlike direct host-plant resistance, indirect host-plant resistance is somewhat restricted in modern cultivars of sugarcane (Falco et al. 2001). This is due to the secondary plant volatiles that sugarcane releases when the stalk is damaged by herbivores (Rutherford and Conlong 2010). While such volatiles might be present upon attack, it is evident that they are not readily identified by natural enemies of *E. saccharina* (Rutherford and Conlong 2010). *Eldana saccharina* has many native natural enemies, but parasitism rates in sugarcane are negligible when compared to the parasitism rates of the pest in its natural host-plants (Rutherford 2014). This is true even when the sugarcane is situated near stands of infested natural host plants in which parasitoids are abundant (Rutherford 2014). This means that parasitoids are unable to recognise the volatiles that sugarcane emits and are therefore unable to identify the stalk borer in the crop. Alternatively, sugarcane may have lost the ability to produce indirect chemical defences against *E. saccharina* (Rutherford and Conlong 2010). This is predicted to have been caused by intensive breeding programs that have primarily concentrated on the expression of direct host-plant defences, resulting in the potential down regulation of indirect defence mechanisms in modern cultivars (Falco 2001, Rutherford and Conlong 2010). To improve natural enemy searching within sugarcane, volatile plant SOS signals and a mixture of synthetic chemical cues could be released within the crop as an indirect form of defence (Khan et al. 2008b, Gurr and Kvedaras 2010). This could improve parasitizing rates and may also help to dissuade pests from entering the crop to search for oviposition sites (Rutherford and Conlong 2010).

1.4.5. Seeking solutions: How can we improve the control of *Eldana saccharina* in sugarcane?

Despite research efforts, *E. saccharina* still remains a highly problematic pest on sugarcane in South Africa (Keeping 2006). This is partially due to the habitat in which *E. saccharina* lives. The large monocultures that characterise sugarcane production are typically unsuitable for populations of beneficial parasitoids and predators of the pest (Altieri 1999). Increasing plant diversity within and around agricultural habitats provides alternate food and sheltering resources, which can be used as a tool to increase the numbers of beneficial natural enemies in the agroecosystem (Altieri 1999). This is important because research has shown that various parasitoids of *E. saccharina* seem unable to locate the eggs, larvae and pupae of the pest within sugarcane (Conlong 1997). The lack of appropriate chemical cues and the availability of cryptic oviposition sites within sugarcane monocultures means that the parasitism of *E. saccharina* within the crop is very low, (Conlong 1997, Rutherford 2014). Monocultured sugarcane also ensures that *E. saccharina* moths are able to disperse more readily into neighbouring fields and farms by providing homogenous habitats that are easy to reach, inter-connected and abundant. Furthermore, ratoon cycles and trashing, allow residual populations of the pest to remain within a field even after it has been harvested (Leslie 1994). The practice of pre-harvest burning destroys natural predators of *E. saccharina* (earwigs, ants and spiders), which would otherwise help to control residual populations of the pest (Leslie 1981). If burning was reduced or stopped a build-up of beneficial organisms would result in better control, allowing farmers to safely trash their cane. Chemicals such as Fastac® are available for use against *E. saccharina*, however the pest is well protected within the stalk and multiple applications of these chemicals are needed for effective control (Leslie 2003). In an industry where the majority of the farmers are small to medium scale growers, this is not a financially viable option (Kfir et al. 2002). Environmental awareness and concern for health amongst consumers has also put pressure on growers to move away from pesticide use as the only means of pest control (Kfir et al. 2002). Pesticide resistance within insect populations is also a consideration, and therefore alternative strategies are preferable (Brattsten 1989). As the popular saying goes, “There is no silver bullet”, and none of the above control methods by themselves provide an adequate solution to problems that *E. saccharina* poses (Conlong and Rutherford 2009). Drawing from recent advances in agricultural research, Webster et al. (2005) proposed the formulation of an integrated pest management (IPM) programme to combat the pest in sugarcane. The programme seeks to use the above techniques in conjunction with other innovative technologies in an integrated, holistic approach (Conlong and Rutherford 2009).

1.5. Integrated Pest Management (IPM)

1.5.1. IPM - A Definition

Integrated pest management (IPM) can be loosely defined as a decision-making process, which based on knowledge of the pest and its tri-trophic and environmental interactions (Kogan 1998, Ehler 2006). It is concerned with using multiple pest management tactics in conjunction with threshold models, for the control of insect pests or diseases in agricultural crops (Kogan 1998, Ehler 2006). The main purpose of IPM is to prevent economically damaging out-breaks of pests, whilst also reducing the risks to human health and the environment through the reduction of chemical insecticides, herbicides and fungicides on crops (Prokopy 2003).

1.5.2. Levels of IPM

Integrated pest management has been the main paradigm that has guided the research and implementation of insect pest management for over 50 years (Furlong and Zalucki 2010). However, IPM means different things to different people and, although the concept of IPM is continually gaining in popularity, risk management and the fear of crop loss often leads to producers adopting limited aspects of IPM (Thomas 1999). Many different concepts and levels of IPM exist and these are roughly distinguished according to the number of pests being controlled and the number of integrated techniques being used (Thomas 1999). Low-level IPM focuses on using basic scouting techniques to estimate pest populations within a crop (Rutherford and Conlong 2010). This information is then used to determine suitable programmes for the prudent use of insecticides according to economic threshold models and the life history stages of the targeted pest (Kogan 1998, Ehler 2006). More advanced IPM practices utilize some additional preventative measures such as cultural controls, plant resistance and notable reductions in broad-spectrum pesticide usage to promote natural enemy abundance (Way and van Emden 2000, Rutherford and Conlong 2010). However, IPM strategies such as these generally target a single pest species and rarely consider multiple pests within a specific agro-ecosystem, not to mention the important interactions between pests and beneficial natural enemies (Ehler 2006, Rutherford and Conlong 2010). Therefore, the creation of 'truly integrated', bio-intensive IPM programmes is preferable (Thomas 1999, Way and van Emden 2000).

1.5.3. Bio-intensive IPM in sugarcane

Bio-intensive IPM programmes use multiple intervention measures for the control of multiple pests within a crop (Ehler 2006, Rutherford and Conlong 2010). For example, the Californian citrus industry is able to suppress a number of insect citrus pests through biological control, reduced pesticide application, and good cultural practices, such as improved field hygiene, resistant varieties, pruning, cover crop development and pest monitoring systems (Ferguson and Grafton-Cardwell et al. 2014). Biological control forms a major part of citrus IPM in this area, and a number of parasitoids and predators are employed for the control of some of the most important citrus pests (Ferguson and Grafton-Cardwell et al. 2014). Integrated pest control techniques play a vital role in reducing the usage of broad-spectrum insecticides, and thereby help to conserve and augment these natural enemies within the agricultural environment (Ferguson and Grafton-Cardwell et al. 2014). California red scale, *Aonidiella aurantii* Maskell (Himiptera: Diaspididae), can be controlled by two parasitoids, *Aphytis melinus* DeBach (Hymenoptera: Aphelinidae) and *Comperiella bifasciata* Howard (Hymenoptera: Encyrtidae), while the cottony cushion scale, *Icerya purchasi* Maskell (Hermiptera: Monoplebidae), and the citrus thrips (*Scirtothrips citri* Moulton (Thysanoptera: Thripidae)) are respectively controlled by the predators *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae) and *Euseius tularensis*

Congdon (Acari: Phytoseiidae) (Grogan 2012). These are just a few of the insect pests within the Californian citrus industry, which are managed through the regional IPM programme (Ferguson and Grafton-Cardwell 2014). Such 'High-level' IPM programmes are "knowledge intensive" and require an in-depth knowledge of pest biology, ecology and behaviour within an agro-ecosystem, as well as a good understanding of species interactions, food webs and energy flows within the surrounding habitat (Hendrichs et al. 2007).

Bio-intensive IPM in the South African sugar industry is based on such holistic agro-ecosystem interactions (Rutherford and Conlong 2010). Research seeks to combine information about sugarcane pests, their symbionts, pathogens, natural enemies, plants, endophytes and the interactions between all of these, to develop a bio-intensive IPM programme in an area-wide, environmentally friendly manner (Rutherford and Conlong 2010). Conlong and Rutherford (2010) reviewed some of the advances in knowledge of sugarcane pests, and of biotic interactions regarding plant resistance, plant nutrition, habitat management, chemical ecology, natural enemies, soil-health, microorganisms, phylogenetics and phylogeography. Such efforts in gaining information are of the utmost importance and have been instrumental in the formation of a bio-intensive IPM programme which has been developed at the South African Sugarcane Research Institute (SASRI). This program was developed to improve the control of *E. saccharina* and other diseases, weeds and pests, such as smut (*Puccinia melanocephala*), rust (*Ustilago scitaminea*), Bermudagrass (*Cynodon dactylon* L. (Poales: Poaceae)), sugarcane thrips (*Fulmekiola serrata* Kobus (Thysanoptera: Thripidae)), white grubs (Coleoptera: Scarabeidae) and various species of nematodes (Campbell et al. 2009, Rutherford and Conlong 2010). Rutherford (2015) provides an outline of the IPM programme that SASRI has developed for the control of *E. saccharina* in sugarcane. The programme aims to integrate all the aforementioned methods of controlling *E. saccharina* using a bottom-up approach that takes into account other pest species, bio-security threats and better management practices (BMP's) (Rutherford 2015). The IPM programme also examines the addition of new innovative technologies such as sterile insect technique (SIT), bio-control through the manipulation of insect pathogens and symbionts, genetic modification of sugarcane and finally, stimulo-deterrent diversion (SDD) or push-pull (Werren 1997, Ako et al. 2003, Snyman et al. 2008, Conlong and Rutherford 2009).

1.6. Stimulo-deterrent diversion / Push-pull systems

1.6.1. Creating a heterogeneous agro-ecosystem

One of the major problems regarding increased pest infestation and failures in pest control methods is the fact that modern agriculture focuses on mass production of individual crops within an agro-ecosystem (Altieri 1991). This tendency towards monoculture creates homogenous environments which are favourable for pests and are ultimately detrimental to farmers (van Emden 1990, Altieri 1991). Habitat management is a form of conservation biological control, which uses an ecologically based approach that aims to enhance natural enemy recruitment and improve biological control in agricultural landscapes (Rodriguez-Saona and Stelinski 2009). Contemporary habitat management is based on techniques which have been practiced for centuries, and which have their roots in basic cultural control methods (Gurr et al. 2004, New 2005). These techniques help to improve biodiversity within the agricultural system, so that a more heterogeneous landscape is created (Gurr et al. 2004). It has been shown that biodiversity is crucial to crop defences (Altieri and Nicholl 2000). Increased diversity amongst plants, animals and soil-borne organisms inhabiting an agricultural environment result in a more diverse community of pest-fighting beneficial organisms that a farm can support (van Emden and Williams 1974, Altieri and Nicholl 2000). Rodriguez-Saona and Stelinski (2009) state that the goal of habitat management is to create a suitable ecological infrastructure within the agricultural landscape to provide resources such as food for adult natural enemies, as well as alternative prey or hosts and shelter from adverse conditions. Research indicates that such resources should be incorporated into the landscape in a way that is spatially and temporally favourable to natural enemies, so that they can provide the maximum benefit to the farmer in terms of biological pest control (Rodriguez-Soana and Stelinski 2009). Practices that form a part of a habitat management approach include green manuring, crop rotation, manipulation of planting and harvesting dates, intercropping, manipulation of plant volatiles and the use of attractive and repellent plants (Barker 2008). Several of these practices can be used together to achieve stimulo-deterrent diversion (SDD) of insect pests (Gurr et al. 2004). Stimulo-deterrent diversion, also known as push-pull, is a type of habitat management, where the focus is to not only increase biodiversity on farms to improve natural enemy populations, but to also manipulate the behaviour of specific pests using components of the agroecosystem (Ehler 1998).

1.6.2. The role of semio-chemicals in push-pull

Semio-chemicals are communication signals that are involved in insect-insect or plant-insect interactions (Heuskin et al. 2011). Semio-chemicals can be regarded as stimuli, which when emitted by an individual, induces a physiological or behavioural reaction in another individual (Wilson 1971). This can be beneficial to the emitter, the receiver or to both individuals (Wilson 1971). Plant species have the ability to emit semio-chemicals when attacked by herbivores, particularly herbivorous insects (Conlong and Kasl 2001). These interspecific semio-chemicals are secondary metabolites called allelochemicals, which are involved in plant communication and plant-protection (Regnault-Roger and Philogene 2008). Herbivore-induced plant volatiles (HIPVs) are allelochemicals that are produced by plants and render the plant unpalatable or act as repellents to insect pests (Conlong and Kasl 2001, Khan et al. 2008a). They also serve to attract the natural enemies of the herbivore attacking the plant (Conlong and Kasl 2001). Whilst HIPVs are generally emitted by damaged plants, some intact plants produce these volatiles either as a warning to other plants in the vicinity or as a natural metabolic by-product (Conlong and Kasl 2001). It is this property that is exploited for the implementation of SDD strategies that aim to manipulate pest behaviour in a way that benefits the farmer (Foster and Harris 1997). The SDD principle is a cropping system, whereby pest repelling plants (push plants) are integrated (intercropped) into the agro-ecosystem to repel pests away from a target crop (Khan et al. 2008b). These push plants are used in conjunction with pest attracting plants (pull plants), which are planted at a slight distance from the intercropped system (Khan et al. 2007b). The 'pull' plants act as a trap crop, luring pests away from the target crop (Gurr et al. 2004, Khan et al. 2007b). The pest can be subsequently removed or destroyed once they are lured into the trap crop (Cook et al. 2007). Push-pull strategies create dynamic, heterogeneous environments where the natural delivery of semio-chemicals helps to reduce pest populations, whilst simultaneously attracting natural enemies (Khan et al. 2007b, Heuskin et al. 2011). The holistic framework that characterises push-pull works well with other IPM techniques, resulting in a conservation biological control (CBC) strategy which, if implemented correctly, ensures the continued suppression of pests within a system (Cook et al. 2007).

1.7. Push-pull – An African perspective

The push-pull method is regarded as a relatively recent approach in pest control, especially compared to other tactics used in IPM (Heuskin et al. 2011). The development of a push-pull strategy for an IPM programme was first achieved in Australia in 1987 through the use of repellent and attractive stimuli to manipulate the distribution of *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) in cotton (Pyke et al. 1987, Khan and Pickett 2008). Since then it has been shown to work well for the control of a variety of pests in many different crop species (Cook et al 2007). Perhaps the most successful push-pull strategy, and the most relevant system with regards to the development of a push-pull strategy in sugarcane, is the programme implemented by the International Centre of Insect Physiology and Ecology (ICIPE) and Rothamsted Research Institute in the United Kingdom (Khan et al. 2001, Cockburn 2013). The programme was developed for the control of lepidopteran stem borers and *Striga hermonthica* (Del.) Benth. (Lamiales: Scrophulariaceae) in small scale maize (*Zea mays* L. (Poales: Poaceae)) farms (Khan et al. 2006).

A major problem in African agriculture is the inability to address the gap between food supply and food demand, which is continuously growing due to increased population growth (Khan et al. 2008b, Pretty et al. 2011). Increasing crop production is an important challenge which, if realised, will not only alleviate hunger and poverty, but also aid in economic growth and help to address environmental degradation in the continent (Khan et al. 2008b). One of the most direct means of improving production is through the control of damaging pests (Pretty et al. 2011). Lepidopteran stem borers, such as *Chilo partellus* Swinhoe (Lepidoptera: Crambidae), *Busseola fusca* Fuller (Lepidoptera: Noctuidae), *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *E. saccharina*, readily infest maize and sorghum (*Sorghum bicolor* (L.) Moench (Poales: Poaceae)), which are considered the most important food crops for millions of the poorest of African farmers (Cook et al. 2007). These pests cause yield losses in crops of approximately 10-50% (Cook et al. 2007). The only recommendations made by agricultural advisory services in the regions is the use of chemical insecticides (Cook et al 2007). However, in Africa, especially amongst subsistence farmers, insecticidal methods of pest control are impractical and more importantly uneconomical (Van den Berg and Nur 1998, Khan et al. 2014). African smallholders can simply not afford to use or apply insecticides (Van den Berg and Nur 1998). As a result, researchers developed a push-pull system that serves as an alternative to chemical insecticides and is helping to improve yields and food security in the region (Cook et al. 2007).

Lepidopteran stem borers are polyphagous pests and previous research has shown that they have a relatively wide host plant range (Ingram 1958, Bowden 1976). This includes many species of wild grasses indigenous to Africa (Ingram 1958, Bowden 1976). Using this information, Khan et al. (1997b) explored the possibility of using wild gramineous plants for the management of lepidopteran stem borers, specifically *Chilo partellus, Eldana saccharina, Busseola fusca* and *Sesamia calamistis,* in Kenya and other African regions. It was found that Napier grass (*Pennisetum purpureum* Schumach (Poales: Poaceae)) and Sudan grass (*Sorghum vulgare* var. *sudanese* Hitchcock (Poales: Poaceae)) attracted gravid female moths (Khan et al. 1997b). In fact, oviposition occurred more frequently on these grasses than on maize or sorghum, showing that they were consistently preferred by the stem borers (Khan 1997a). This preference, coupled with a high larval mortality rate on the preferred host plants, meant that the plants could be effectively used as trap crops for the pests (Khan 1997a, Khan et al. 2006). In addition to this, other plants such as the grass *Melinis minutiflora* P. Beauv (Poales: Poaceae) and legumes in the genus *Desmodium*, were found to attract no oviposition (Khan et al. 1997a, Khan et al. 2000), being repellent to gravid stem borer moths (Khan et al. 1997a, Khan et al. 2000). This led to the adoption of a push-pull system where *M. minutiflora* and *Desmodium uncinatum* (Jacq.) DC. (Fabales: Fabaceae) were intercropped with maize to repel (push) the same species of lepidopteran stem borers as mentioned above (Khan et al. 1997a, Khan et al. 2014). Napier or Sudan grass was planted as a border around maize plots to attract (pull) the pests (Khan et al. 2014). This has resulted in the reduction of stem borer infestations by over 80 % in maize growing areas (Khan et al. 2014). The program has been rolled out and the adoption of push-pull has now grown to be used by up to 70 000 small-scale subsistence and medium-scale farmers in East Africa (Khan et al. 2014).

The success of push-pull in Kenya and the surrounding countries can be attributed to fact that maize yields have drastically improved in the area, however other factors have also made push-pull appealing to farmers (Khan et al. 2014). Farmers in this region rely on a diversity of crops and livestock and regularly practice crop rotation and intercropping (Khan et al. 2014). This means that they are familiar with this type of farming and therefore push-pull is relatively easy for them to implement (Khan et al. 2014). Furthermore, the plants used in push-pull have multiple uses that benefit the growers beyond the manipulation of pest populations (Fischler 2010). Molasses grass (*M. minutiflora*) can be used as fodder for cattle and goats, whilst silver-leaf Desmodium (*D. uncinatum*) is a forage legume that simultaneously improves soil health and reduces the emergence of *S. hermonthica* in maize (Fischler 2010, Khan et al. 2011) Napier grass has anti-feeding properties that reduce stem borer survivability and it also attracts the natural enemies of the pest into the environment so that pest populations are further reduced (Khan et al. 1997a, Khan et al. 2006). Molasses grass similarly attracts and improves the foraging activities of the parasitoid wasp *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae), which is then able to locate and attack *C. partellus* and *B. fusca* in maize (Khan et al. 1997b). Ultimately push-pull has given East African farmers a means of improving their livelihoods and diversifying their farming systems in a cost effective and environmentally friendly way (Cook et al. 2007, Khan et al. 2011).

1.8. Push-pull as part of an IPM programme in sugarcane

The push-pull system in East Africa provided a framework for the development of a similar system for the control of *E. saccharina* in South African sugarcane (Kasl 2004, Barker et al. 2006). Their research showed that such systems worked well for the control of related cereal stem borers and could perform successfully within an African context (Barker 2008, Khan et al. 2014). Previous research into the indigenous wild hosts of *E. saccharina*, its biology and the prevalence of natural enemies within these hosts formed the basis of the habitat management strategy that was developed for this pest (Atkinson 1980, Conlong 1990, Conlong and Kasl 2000). This information, and that garnered from the work done in Kenya, provided a number of potential push and pull plants, which were subsequently tested for suitability against *E. saccharina* in both laboratory and field experiments (Kasl 2004, Barker 2008, Cockburn 2013). Special attention was paid to plants which produced the necessary semio-chemicals to attract/repel *E. saccharina*, as well as those plants that were able to increase the efficacy of parasitoids within the agro-ecosystem (Conlong and Kasl 2001, Kasl 2004). It was specifically important for the researchers to identify potential push-pull plants that could be readily sourced in South Africa.

Cage trials and on farm field trials indicated that *P. pupureum*, *S. bicolor*, *C. dives* and *C. papyrus* were all attractive to gravid *E. saccharina* moths (Kasl 2004, Conlong et al. 2007). Unfortunately, *S. bicolor* had to be excluded as a push-pull plant due to its potential as a weed which may compete for resources with sugarcane (Kasl 2004). After further testing, Conlong et al. (2007) found that female *E. saccharina* moths will accept indigenous host plants for oviposition more readily than sugarcane. The study showed that *C. papyrus* and *C. dives* were significantly preferable to *E. saccharina* than *P. purpureum*, with sugarcane being least preferred (Conlong et al. 2007, Rutherford and Conlong 2010). This demonstrated the hierarchical oviposition preference of *E. saccharina* (Conlong et al. 2007). The pest tends to oviposit on indigenous sedges first, then wild grasses and finally non-native crops such as sugarcane (Conlong et al. 2007). Furthermore, fields of sugarcane growing adjacent to stands of *C. papyrus* and *C. dives* were shown to have significantly less *E. saccharina* damage than control fields, thereby confirming the effectiveness of sedges as attractant (pull) plants for the African sugarcane stem borer (Kasl 2004, Rutherford and Conlong 2010). Keeping et al. (2007) also revealed that, if given the choice between older sugarcane and older maize, *E. saccharina* would oviposit on maize. Preference for maize was still evident, even if *E. saccharina* was offered *Bt*-maize (Keeping et al. 2007). *Bt*-maize contains *cry* genes isolated from the bacterium *Bacillus thuringiensis* Berliner (Bacillales: Bacillaceae) and is thus able to express the insecticidal *Bt*-protein (Keeping et al. 2007). Larvae that attack the maize ingest the protein and are subsequently killed (Keeping et al. 2007). *Eldana saccharina* larval survival on *Bt*-maize was found to be zero percent and as such, *Bt*-maize was identified as another pull plant, which could also act as a 'dead end' trap crop (Khan et al. 2000, Keeping et al. 2007).

Despite the effectiveness of the above pull plants, Conlong et al. (2007) showed that female *E. saccharina* moths have a tendency to choose cryptic oviposition sites over these more suitable host plants. This behaviour can result in oviposition occurring on crops even when more attractive alternative hosts are available (Rutherford and Conlong 2010). Oviposition by *E. saccharina* was seen to occur when cryptic oviposition sites were available in the vicinity of acceptable host plants (Conlong et al. 2007). It is evident that female moths merely decide on laying sites that may help to prevent predation and that it is actually the mobile, neonate larvae that choose which hosts to feed on (Conlong et al. 2007). In on-farm situations, *E. saccharina* moths may choose to oviposit on sugarcane rather than *C. papyrus* or *C. dives*, because the dead leaves on older sugarcane stalks provide better cryptic oviposition sites for eggs to be laid (Conlong et al. 2007). To prevent adult females from ovipositing on the crop, a 'push' factor can be introduced into the system. As discussed earlier, *E. saccharina* and other insect pests can be repelled by non-host or 'push' plants that naturally produce HIPVs (Khan et al. 2007a). The presence of plants that emit these volatiles indicate to the insect that the potential host plants, within the immediate region, are already infested and therefore unsuitable as oviposition sites. (Khan et al. 2007a).

Melinis minutiflora is able to repel *E. saccharina* in this way. Not only is it repulsive to a number of Lepidopteran stem borers, it also has parasitoid attracting properties (Cook et al. 2007). Molasses grass has the ability to produce volatiles similar to those produced by damaged maize, even in the absence of pest damage to itself (Khan et al. 1997a). There are different varieties of the grass, and although Kenyan *M. minutiflora* (as used in the successful East African push-pull program) is the most effective variety, Kasl (2004) found that the South African variety of molasses grass also works well to simultaneously repel *E. saccharina* and attract its natural enemies. This was confirmed, when damage by *E. saccharina* was reduced by 50% in sugarcane plots that were planted next to strips of South African *M. minutiflora,* compared to control plots, suggesting that the pest can be successfully repelled by molasses grass volatiles (Barker et al. 2006). Unlike the pull plant *S. bicolor*, *Melinis minutiflora* is safe to use in the sugarcane agro-ecosystems because it is not shade tolerant and therefore does not encroach into sugarcane fields (Barker et al. 2006, Conlong and Campbell 2010). This means that it does not compete with sugarcane for resources (Barker et al. 2006). The grass also helps to suppress problematic weeds and can be used or sold as a fodder crop (Barker et al. 2006, Conlong and Campbell 2010, Khan et al. 2014). *Melinis minutiflora* is relatively drought resistant and will not require frequent watering, this is important for sugarcane farmers who live in areas where rainfall is already a limiting factor (Barker et al. 2006). In addition to this, experiments at SASRI, successfully demonstrated that *M. minutiflora* is able to improve the searching ability of natural enemies, the parasitoid *X. stemmator* parasitized more *E. saccharina* pupae in sugarcane that was grown in close proximity to *M. minutiflora* (Kasl 2004, Rutherford and Conlong 2010). The figure below depicts a diagram of PPT and its integration into the sugarcane agroecosystem.

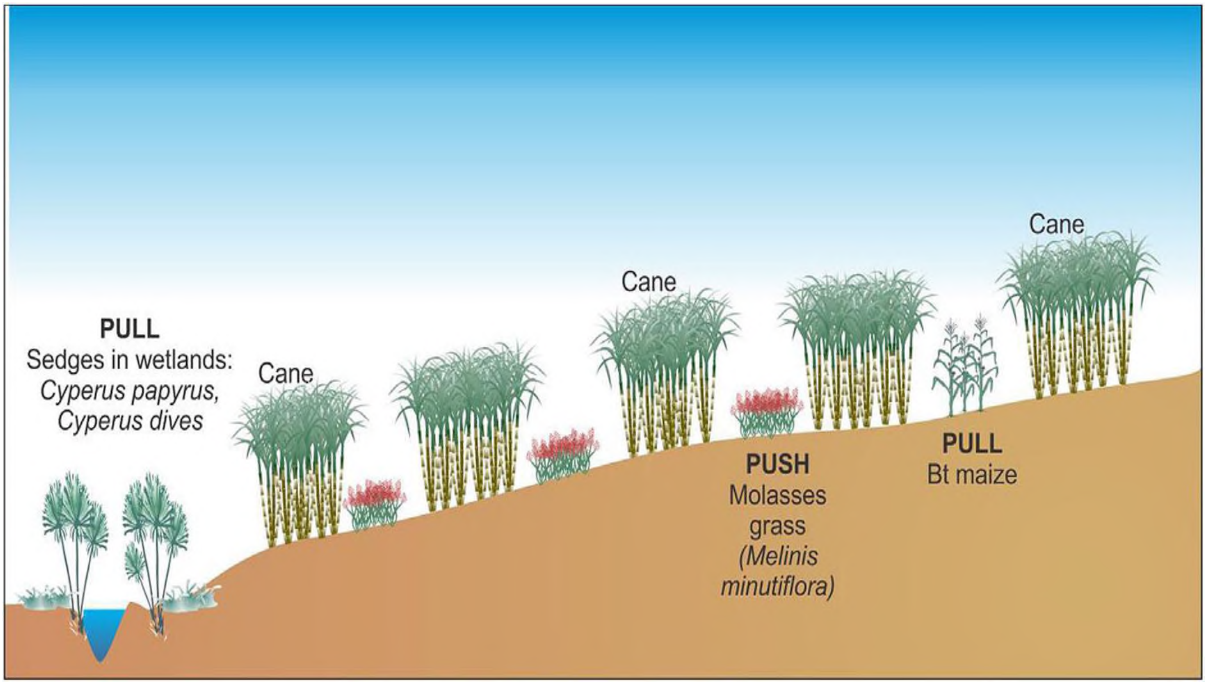


Figure 1.1. Diagram of the push-pull strategy recommended for the control of *Eldana saccharina* in sugarcane (Cockburn et al. 2014).

Through intensive research, a farm-based habitat management plan to manage *E. saccharina* populations was developed (Conlong and Rutherford 2009). The plan incorporates the indigenous host plants *C. papyrus* and *C. dives* together with *Bt*-maize as 'pull' plants, and *M. minutiflora* as the 'push' component (Rutherford and Conlong 2010). Augmentation of natural enemies has also commenced, with parasitoids being reared in the laboratory and released into rehabilitated wetlands, which often form an integral part of push-pull agro-ecosystems. Here the released parasitoid populations can seek out and attack *E. saccharina* more efficiently. This push-pull and CBC approach has been expanded into a biointensive-IPM plan, which incorporates plant nutrition, soil health and the use of less susceptible sugarcane varieties, all to promote the recruitment of indigenous pests, whilst also ensuring a reduction in *E. saccharina* numbers (Rutherford and Conlong 2010, Rutherford 2015).

1.9. Adoption of push-pull by sugarcane farmers

Despite sound research and proven successes, the adoption of innovative IPM techniques and practices is typically slow. (Lee 2005, Hendrichs et al. 2007). This is often due to a lack of implementation incentive, poor support and technical training, over reliance on pesticides and farmers' predisposition towards risk aversion (Parsa et al. 2014). The same can be said about the implementation of push-pull technology (PPT). Cook et al. (2007) found that out of 20 reviewed push-pull programmes, only 2 were being successfully implemented. This can be attributed to a number of factors, which affect the dissemination and adoption of PPT. The knowledge intensive nature of PPT makes it particularly difficult for farmers to understand the mechanisms of push-pull and the benefits that it can provide with regards to their farms and the greater agro-ecosystem (Cook et al. 2007). The lack of information, training and legislation governing IPM systems in South Africa is a particular hindrance to the adoption of new technologies such as PPT (Webster et al. 2005). Farmers in developing countries also tend to doubt the ability of IPM practices to successfully control insect pests (Parsa et al. 2014). As mentioned above, there is also a shortage of incentive to employ PPT (Morse 2009, Parsa et al. 2014). Why should growers invest precious time and money on practices, which, in their view, are unlikely to provide meaningful results? As an answer to the question of why so few sugarcane farmers are adopting PPT, Cockburn (2013) suggested that we revise the way that we approach the transfer of technology (ToT) between researchers and growers from conventional extension methods to a more participative model.

1.9.1 Shifting paradigms and putting the farmer first

Due to the extent and *E. saccharina* infestations, an area wide (AW) approach using push-pull and IPM as a whole is suggested as a necessary means of achieving a good level of *E. saccharina* control (Conlong and Rutherford 2009). An AW approach requires the cooperation and collaboration of multiple stakeholders including researchers, extension teams, policy makers, government officials, community members and farmers (Hendrichs et al. 2007, Cockburn 2013). Typically, tactics for facilitating the implementation of agricultural innovations, such as AW-IPM programmes, have followed linear models of dissemination (Stephenson 2003, Godin 2006, Knickel et al. 2009). The ToT model (linear model of innovation) and the diffusion of innovations model are amongst the most prevailing paradigms in extension of agricultural information, knowledge and technology (Stephenson 2003, Rogers 2004, Godin 2006). Such models adopt a diffusion theory, whereby the ToT and knowledge is regarded as linear, progressing from conception to adoption as if by osmosis (Leeuwis 1993, Pretty and Hine 2001, Knickel et al. 2009). This is considered a top-down approach, which assumes that scientists hold the key to information (Leeuwis 1993, Cockburn 2013). The information, developed through basic and applied research, is allowed to trickle down, using extension services as a conduit, to innovative farmers, who can then use the knowledge to improve productivity (Leeuwis 2004). A combination of the success of new innovations and the influence of adopting farmers allows for further diffusion of information to laggards or late adopters (Diederen et al. 2003). While linear models of innovation may seem effective, they have been widely criticised (Leeuwis 1993, Knickel et al. 2009, Khan et al. 2008a, Cockburn 2013). They are useful for understanding the basic mechanisms of research and innovation and the roles that learning and decision-making play in the applied sciences (Balconi et al. 2010). However, they are over simplified and are therefore only appropriate for the transfer of simple technologies and chemically based control methods, which are not knowledge intensive and do not involve the application of multiple integrated control practices (Röling and van de Fliert 1994, Klerx et al. 2012, Balconi et al. 2010)

The main issues regarding linear models and their use as a tool for disseminating agricultural innovations is that the flow of information is unidirectional from scientist (innovator) to farmer (adopter) (Cockburn 2013). Because of this, there is a tendency among scientists and extension specialists to assume that agricultural innovations are positive, and that rejection of new technologies is negative (Stephenson 2003, Röling et al. 2012). Non-adopters are considered as inferior, despite the reasons and circumstances behind their rejection of the innovation (Stephenson 2003). Since all individuals and farms are different, new technologies are not always suited to a grower's needs (Stephenson 2003, Röling et al. 2012). Growers should be able to communicate their needs, misgivings and ideas to extension officers and researchers so that technologies can be revised and tailored to suite the individual farmers' situation (Röling et al. 2012). In short, the flow of information in implementation schemes needs to be multidirectional, with farmers contributing equally towards the development of knowledge (Leeuwis 2004, Klerx et al. 2012). The farmer should be seen as an active role player (Cockburn 2013). They must be regarded as the solution to, and not the problem of, implementation issues (Leeuwis 2004). This can help to improve the adoption rates of new, knowledge intensive and complex agricultural innovations such as AW-IPM and push-pull (Cockburn 2013).

1.9.2. Farmer learning and farmer perceptions: Lessons from ICIPE

Khan et al. (2008a, 2008b) found that successful adoption of AW push-pull in Kenya was heavily reliant on active participation by farmers and other stakeholders. An evaluation of farmers' perceptions and knowledge regarding pests and push-pull revealed important information regarding their motivations for adoption (Khan et al. 2008a). This information formed an essential part of the successful implementation of a push-pull system in the region (Khan et al. 2014). The value of participation by all stakeholders is discussed by numerous authors, leading to the development of new approaches and methodologies that have proven relevant in many different rural agricultural programmes (Röling and van de Fliert 1994, Cockburn 2013). Such methods have been developed with the help of social scientists and can lead to a better understanding of farmers' constraints and other factors that are considered as limiting to the adoption of new technologies, so that they can be addressed as part of the programmes in question (Cockburn 2013). This represents a more interdisciplinary, farmer-first approach to agricultural adoption processes and creates a scenario where scientists develop IPM programmes with the farmer rather than for them (Thompson and Scoone 1994).

Experiential and social learning were also found to be necessary in the development of new participation approaches to rural innovation (Pretty 1995, Rolling and Jiggins 1998, Meir and Williamson 2005). Farmer field schools (FFSs) were first developed in South East Asia as a response to outbreaks of the brown plant hopper, *Nilaparvata lugens* Stal. (Himiptera: Delphacidae) (Röling and Van de Fliert 1994, Braun and Duveskog 2008). The outbreak, which led to major losses in the rice industry, was mainly caused by the application of pesticides that destroyed natural insect predators of the pest (Khisa 2002). The solution was the development of an intensive IPM programme that focused on the reduction of pesticide applications (Matteson 2000, Khisa 2002). To improve the adoption and overall effect of this IPM programme, a farmer training plan was created using FFS's (Röling and van de Fliert 1994, Matteson 2000, Ooi et al. 2005). These FFSs were a radical departure from typical extension activities of the time (Khisa 2002, Braun and Duveskog 2008). In the FFS's, farmers were not instructed on what to do, but rather empowered through education to handle their own on-farm decisions (Matteson 2000, Khisa 2002). The schools encouraged farmers to investigate and learn for themselves the skills required for, and the benefits gained from, the adoption of IPM practices (Matteson 2000, Khisa 2002, Ooi et al. 2005). Since then FFSs have been replicated, tailored and used in multiple agricultural programmes (Braun and Duveskog 2008, Khisa 2002). The empowerment of farmers helps them to make more informed decisions, improves their resilience and lessens their reliance on external inputs (Röling and Wagemakers 1998). Experiential and social learning is particularly successful for the empowerment of female farmers, small-scale rural farmers and farmers with poor education (Pretty 1995, Davis et al. 2012, Cockburn 2013).

Some of the main pathways of technology dissemination in the Kenyan push-pull project involved experiential and social learning (Khan et al. 2014). Khan et al. (2008b) found that interacting in any dissemination/extension methods increased the likelihood of farmers adopting PPT. This likelihood was greatly improved if the farmer was involved in FFSs, field days or had contact with farmer teachers (Khan et al 2008a). Farmer teachers are progressive farmers, who are able to influence other farmers to adopt new technologies and practices (Amudavi et al. 2009). This farmer-to-farmer extension strategy allows for the sharing of new information and learning experiences (Amudavi et al. 2009). Researchers also used mass media, public meetings and printed materials to spread the word of push-pull and its benefits (Khan et al. 2008a). It was discovered, by Khan et al. (2008a), that a farmer's particular location, background, age and education influenced their preferred method of learning. Once again, the importance of considering the effect of multiple factors on farmer tendency towards adoption is evident (Braun and Duveskog 2008). The necessity to change one's approach to suit individual situations is a key factor in the implementation of IPM technologies (Cockburn 2013). Khan et al. (2008a), also found that contact with innovative farmers improved adoption of push-pull in western Kenya. Farmers tend to listen to other farmers (Braun and Duveskog 2008). If growers are able to see technologies in practice, and hear first-hand of their benefits from someone they understand and trust, they are more likely to adopt such technologies on their own farms (Braun and Duveskog 2008). As such, farmers themselves were important in the facilitation of push-pull in East Africa (Khan 2008a, Khan et al. 2014). This more than anything else highlights the fact that scientists and extension workers need to recognise the influence of early adopters in the farming community, and work with them and other farmers to improve adoption and ultimately regional productivity.

1.9.3. Cockburn (2013): Applying these lessons to improve push-pull adoption in the Midlands North

Drawing from research discussing the importance of farmers' perceptions, and local studies exploring the production constraints of small-scale maize farmers, Cockburn (2013) set out to investigate the adoption of PPT by sugarcane farmers in the Midlands North region of KZN. Her research featured diagnostic studies (as described by Röling 2004), which helped to understand agricultural systems, farmer constraints, their innovative capacities and how these relate to the adoption of IPM technologies such as push-pull. She worked with both large-scale growers (LSGs) and small-scale growers (SSGs) in this region (Cockburn et al. 2012, Cockburn 2013, Cockburn et al. 2014).

SSGs in the midlands north were found to rely on a complex of crops and livestock, which are mixed farmed (Cockburn et al. 2014). Of the wide-range of crops grown, sugarcane played an important role and was found to be an integral part of the livelihood of farmers in this area, providing both employment and income to a large number of people in the Noodsberg region (Cockburn et al. 2014). SSGs identified weeds and high-input costs, such as the price of fertilizer, as their major production constraints (Cockburn 2013). Pest control was not a priority for these farmers and *E. saccharina* numbers were negligible on their farms (Cockburn 2013). As such, Cockburn suggested that the implementation of push-pull for the control of *E. saccharina* amongst SSGs in the Midlands North area was not a main concern, and that resources should be invested elsewhere, perhaps towards weed management (Cockburn 2013). She recommended that extension specialists prioritise weed management for SSGs, perhaps using push-pull complimentary components, such as the creeping grass control capacity of *M. minutiflora* (Conlong and Campbell 2010), the components of which may prove useful if *E. saccharina* levels in the Midlands North area continue to increase (Cockburn 2013). SSGs in the Midlands North area are similar to those farmers involved with the push-pull system in Kenya, in that their farms are diverse and mixed, meaning that habitat management is something that they can readily identify with (Cockburn 2013, Khan et al. 2014). Cockburn (2013) concluded her SSG study saying that even though push-pull wasn't an exact fit for the farmers in her study area, their farms should continue to be monitored, as *E. saccharina* populations continue to increase in the region. FFSs should still be used to improve the knowledge and skills of SSGs as a means of increasing sugarcane production for the benefit of both the mills and the household incomes and food security of the greater community (Cockburn 2013).

Cockburn et al. (2014) found that LSGs had good basic knowledge of IPM and push-pull and many of them regarded it as an effective means of controlling *E. saccharina*. However, they still lacked detailed information regarding the mechanisms and benefits of push-pull, and they did not know how to commence its implementation on their own farms (Cockburn et al. 2014). Many of them did not know where to buy push-pull plants or how these plants were able to manipulate *E. saccharina* populations (Cockburn et al. 2014). This pointed to a dearth in their push-pull knowledge. Furthermore, farmers' perceived push-pull as time consuming and were unwilling to pay for the costs of implementation, particularly since the Midlands North is a traditionally low *E. saccharina* area due to frost and low winter temperatures (Assefa et al. 2008, Cockburn et al. 2014). In other words, despite accepting the fact that *E. saccharina* populations are spreading and pose a real risk to their farms, many LSGs did not feel that it was necessary to use control methods to reduce their numbers, or to prevent new infestations (Webster et al. 2005, Assefa et al. 2008, Cockburn et al. 2014). When consulted, farmers indicated that their preferred method of learning about new technologies was through the use of model farms and field days (Cockburn et al. 2014). Using this information, researchers, SASRI extension specialists and the local pest, disease and variety control committee (LPD&VCC) were better able to educate LSGs in the Midlands North area about the details of PPT and demonstrate that it is a relatively low cost and time efficient intervention to implement. They were also able to market the technology as a preventative rather than reactive means of controlling *E. saccharina*. This, coupled with the fact that *E. saccharina* numbers have drastically increased in the Midlands North area in the last few years, has resulted in increased adoption of PPT in the region (T. Webster, pers. comm. 15 August 2015). LPD&VCC have reported that approximately 65 LSGs have started implementing the pull factor of push-pull and are now growing sedges (*C. papyrus* and *C. dives*) on their farms (T. Webster, pers. comm. 15 August 2015). A further 20 farmers have also planted *M. minutiflora* and *Bt*-maize on their farms, meaning that they have successfully put push-pull programmes into place (T. Webster, pers. comm. 15 August 2015). Push-pull was also integrated well with the SUSFarms (Sustainable sugarcane farm management systems) and BMP programmes in this area (Cockburn 2013). These aim to provide farmers with the tools to monitor their own progress with regards to agricultural and on farm sustainability and ecological improvements (Maher 2007, Cockburn 2013). LPD&VCC in the Midlands North region, together with local model farmers, regularly host field days on their farms to teach others the benefits of PPT (T. Webster, pers. comm. 15 August 2015). This displays the farmers' willingness to engage in the new research and initiate experiential learning scenarios.

1.9.4. What about coastal sugarcane farmers?

Despite the ongoing success of push-pull in the Midlands North area, uptake of this technology has been very slow in other areas of the sugarcane industry. There has been little to no response to push-pull in the coastal regions of KZN, even though *E. saccharina* numbers in this region are very high and cause real losses in yield, regardless of early harvesting and varietal control (Assefa et al. 2008, Barker 2008). Farmers seeking to improve their returns by growing carry-over cane are usually forced to use insecticides (Leslie 2009, Ramburan et al. 2009). As discussed earlier this does not provide an adequate solution to the *E. saccharina* problem and may even lead to resistance and increased infestations of not only *E. saccharina,* but other sugarcane pests such as *S. calamistis*, sugarcane thrips (*Fulmekiola serrata* (Thysanoptera: Thripidae)), white grub species (Coleoptera: Scrabaeidae) and yellow sugarcane aphid (*Sipha flava* Forbes (Himiptera: Aphididae)) (Whalon 2008). Considering the problem that *E. saccharina* causes on the coastal belt, researchers are unsure why farmers have been unreceptive of push-pull and IPM in general in that region.

1.10. Aims and objectives

The majority of research regarding push-pull has been conducted in the Midlands North sugarcane growing region of KZN (Webster et al. 2005, Barker et al. 2006, Barker 2008, Webster et al. 2009, Cockburn 2013) with some work showing considerable benefits of push-pull in *E. saccharina* control in the Gingindlovu area (Barker et al. 2006), and Pongola (Kasl, 2004). The poor adoption of PPT amongst coastal sugarcane farmers is thought to be the result of a lack of push-pull research being done in this area. Because of this, it is likely that farmers don't understand push-pull and are therefore unwilling to adopt it. It has also been predicted that coastal farmers lack confidence in push-pull because it has mostly proven successful in an area where *E. saccharina* counts are typically low, and where they don't present a major production constraint (Barker 2008, Cockburn 2013). LPD&VCC in the coastal regions report that farmers doubt that such holistic methods will be able to control the high levels of *E. saccharina* that they experience. It is often perceived that chemical measures are the only way to control critical pest numbers and chemicals are also seen as a quick and easy fix (Ehler 2006). However, this is speculation and we cannot determine the reasons why sugarcane farmers have not adopted push-pull along the coast without further research into their production constraints and their perceptions of push-pull and pests.

The main aim of this research was to improve the implementation of push-pull for the management of *E. saccharina* in sugarcane in the coastal regions of Kwa-Zulu Natal. This was done by developing a better understanding of the efficacy of PPT in the North and South Coast of KZN, and by assessing the feasibility of this technology for use by farmers in the area. The following objectives were used to achieve the goals of the study.

1.10.1. Objectives:

The first objective was to set up push-pull model farms in different areas along both the North and South Coast sugarcane growing regions of KZN. Here the effects of push-pull on populations of *E. saccharina* were monitored to determine the on-farm efficacy of this technology in coastal sugarcane growing regions.

The second objective was to review, tailor and improve the working model for the implementation of push-pull in the Midlands region, as developed by Cockburn (2013), to better suit the needs and management activities of coastal sugarcane farmers. This was done through interviews with large-scale farmers and by assessing the results of PPT on the model farms as discussed in the first objective.

The third objective was to conduct surveys to determine large-scale sugarcane growers' knowledge and perceptions of *E. saccharina* and other pests, as well as other production constrains, pest control methods, IPM and push-pull. Large-scale farmers perceptions of drivers and barriers of push-pull along the coastal sugarcane belt were also included in this objective, and potential solutions to implementation issues were also discussed.

Although push-pull was deemed unnecessary for small-scale sugarcane growers in the Midlands north region, due to very low pest populations, it was predicted that small-scale farmers along the coast would be much more affected by *E. saccharina* and insect pests in general. Therefore, the fourth objective was to conduct field days and interviews amongst small-scale sugarcane farmers based along the coastal sugarcane belt. Their production constraints and perceptions of pests, pest control and push-pull were assessed and the feasibility of PPT for use by small-scale growers was analysed. The potential for allocating resources towards the development of a push-pull programme for small-sugarcane growers was determined.

Methodology for this research was closely related to the studies conducted by Cockburn (2013) so that our results were comparable. This will lead to the development of an improved knowledge base for the facilitation of push-pull into other sugarcane production regions.

1.10.2. Thesis structure

Chapter 1 of this study serves as a general introduction and literature review of sugarcane growth in South Africa, *E. saccharina* biology and pest status, *E. saccharina* pest management tools, and the implementation of push-pull and integrated pest management for the control of this insect. The aims and objectives of this study are also discussed in the first chapter. In Chapter 2 the use of on-farm field trials to determine the efficacy of push-pull is discussed. Five farms were identified in the North and South Coast of KZN and push-pull trials were conducted in sugarcane fields with the help of the model farmers. The efficacy of push-pull was determined by measuring *E. saccharina* populations and damage levels in push-pull treatment and control sites on the five model farms. In Chapter 3 and 4, large-scale farmers' and small-scale farmers' production constraints, knowledge and perceptions of *E. saccharina* and pest management are explored. This was done to facilitate the implementation of push-pull in the coastal sugarcane growing regions. In Chapter 3 the adoption of push-pull by large-scale growers in the North and South Coast region is also evaluated and factors relating to the barriers and drivers of push-pull and IPM adoption are examined. Chapter 5 presents the general conclusions of the study and the limitations of the study are discussed along with suggestions for further research relating to the implementation of push-pull in South African sugarcane.

Chapter 2

Determining the efficacy of push-pull for the control of *Eldana saccharina* on coastal farms in Kwa-Zulu Natal through on-farm field trials.

2.1. Introduction

Eldana saccharina Walker (Lepidoptera: Pyralidae), an indigenous insect, is one of the most damaging stem borers of sugarcane crops in southern Africa. It is estimated that this insect pest causes yield losses in excess of R900 million per year in South Africa alone (Zhou & Mokwele 2015). In response to increasing *E. saccharina* levels, the South African Sugarcane Research Institute (SASRI) has developed an area-wide integrated pest management (AW-IPM) plan for the control of the stem borer in sugarcane (Rutherford & Conlong 2010, Rutherford 2015). The development and implementation of a push-pull strategy for the control of *E. saccharina* forms an important part of the AW-IPM approach as outlined by Rutherford (2015) (See Chapter 1).

The push-pull strategy in sugarcane is a habitat management method of pest control, which is used as a component of AW-IPM (Conlong and Rutherford 2009). It makes use of plants that are both repellent and attractive *to E. saccharina* (Kasl 2004, Barker et al. 2006). This push-pull technology (PPT) is based on a strategy that was developed for the control of cereal stem borers such as *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) and *Busseola fusca* Fuller (Lepidoptera: Noctuidae), in *Zea mays* L (Poales: Poaceae) in East Africa (Khan et al. 1997a, Midega et al. 2005). The 'push' or repellent plant used in this strategy is *Melinis minutiflora* P. Beauv (Cyperales: Poaceae), also referred to as Molasses grass (Kasl 2004, Barker 2008, Cockburn 2013). Molasses grass naturally produces volatile plant defence chemicals (Khan et al. 2000). These chemicals repel the egg-laying adults of targeted stem borers, whilst simultaneously attracting beneficial natural enemies of the pest (Khan et al. 1997a, Kasl 2004, Barker 2008).

Since *E. saccharina* is an indigenous pest, its natural host plants can be used as 'pull' or attractant plants. *Eldana saccharina's* host plants include a variety of wetland species in the families Cyperaceae, Poaceae and Juncaceae. Thus, plants in these families were tested for their ability to attract *E. saccharina* (Conlong 2001, Kasl 2004). Gravid *E. saccharina* moths showed a significant ovipositional preference for *Cyperus papyrus* L. and *Cyperus dives* Delile (Cyperales: Cyperaceae). These species were selected as the most effective 'pull' plants for use in PPT (Kasl 2004). *Eldana saccharina* moths also show a strong ovipositional preference for conventional maize and *Bt*-maize (Keeping et al. 2007). These can be used as alternative 'pull' plants in areas where wetland sedges cannot be planted (Keeping et al. 2007). Furthermore, *Bt*-maize can be used as a dead-end trap crop, because it does not support the larval development of *E. saccharina*, or any other lepidopteran stem borers. The crop produces a *cry* protein that is toxic to any larvae that ingest it (Khan et al. 2000, Keeping et al. 2007).

Initial research into the development of PPT was completed at SASRI by scientists and postgraduate students in laboratories, cage trials and small field trials, where conditions could be observed and controlled (Kasl 2004, Barker et al. 2006, Barker 2008). The research has since progressed to include large-scale on farm field trials in the Midlands North sugarcane growing region of Kwa-Zulu Natal (KZN) (Cockburn 2013). During these trials, Cockburn (2013) demonstrated that the push-pull strategy is effective on large-scale farms, where variables such as soil type, sugarcane variety, sugarcane age and water availability cannot be controlled as efficiently as they can be on small trial plots. Subsequent to the completion of her research, PPT has been adopted by a number of Midland's North large-scale farmers (LSGs) and they have been implementing, planting and maintaining their own push-pull systems independently with the help of the local pest, disease and variety control committee (LPD&VCC) (Cockburn 2013, Webster, pers. comm. 15 August 2015). The increased uptake of PPT following the on-farm field trials, follows work done in Khan et al. (2008), which showed that the implementation of push-pull by small-scale maize farmers in Kenya improved with the introduction of farmer managed field trials. Farmer to farmer technology dissemination means that 'early adopting' farmers are able convey the benefits of new practices and the suitability of these practices to their own farming conditions, thereby influencing other growers to adopt innovative technologies (Amudavi et al. 2009). LPD&VCC in the midlands north area has reported that field trials, farmer days, farmer groups and extension support in the area have all contributed to improved PPT dissemination (Conlong et al. 2016). Approximately 65 LSGs have started implementing the pull factor of push-pull and are now growing sedges (*C. papyrus* and *C. dives*) on their farms and an additional 20 farmers have also planted *M. minutiflora* and *Bt*-maize on their farms, meaning that they have successfully put push-pull programmes into place (Webster, pers. comm. 15 August 2015).

Despite successful research and increasing adoption rates in the Midlands North region, the implementation of AW-IPM and PPT in other sugarcane growing regions of KZN has been slow. The majority of the research focusing on PPT as a tool for controlling *E. saccharina,* has been conducted at the SASRI research facility, or in the Midlands North, with very few studies branching off into other regions of the province (Kasl 2004, Barker 2008, Cockburn 2013). Currently, no large-scale, on farm field trials have been completed in other areas of the province. This is problematic, because while the Midlands North region provided a good base for the development of PPT, *E. saccharina* levels in this area are typically lower when compared to other sugarcane growing regions (Assefa et al. 2008, Cockburn et al. 2014). Sugarcane farmers along the coastal belt of KZN experience much higher levels of *E. saccharina*, resulting in higher crop losses (Assefa et al. 2008). Here, growers are forced to harvest their sugarcane much earlier than the recommended 18-24 months, even with careful varietal control (Assefa et al. 2008, Barker 2008, Rutherford 2015). Insecticides can be used to increase sugarcane age before harvest by lowering *E. saccharina* numbers, however this is expensive, and non-target effects, as well as insect resistance, means that insecticides do not provide an adequate solution (Whalon 2008, Leslie 2009, Ramburan and McElligott 2009). The lack of an effective control method for *E. saccharina* in the coastal regions of KZN should lead to a willingness to employ alternative methods of pest control. However as mentioned previously, this has not been the case.

Researchers investigating the adoption of sustainable agricultural practices in the United States, have found that a major barrier preventing the dissemination of new pest control methods is a perceived lack of efficacy of these practices (Rodriguez et al. 2008). Farmers doubt whether IPM will work on their farms and whether it will be effective in their climates, on their soils and with their management practices (Rodriguez et al. 2008). Furthermore, many farmers are unwilling to risk their profits and their livelihoods by implementing new unknown practices (Pannell 2003). They would rather rely on tried and tested methods such as insecticidal applications, even if these methods are imperfect (Munyua 2003). This is particularly true in regions where pest levels are historically high or especially damaging to crops (Rodriguez et al. 2008). Rodriguez et al. (2008) observed that there was a widespread call for 'good successful examples' of IPM programs in practice. The fact that not enough farmers were adopting sustainable techniques was found to be a deterrent to further adoption (Rodriguez et al. 2008). Farmers want 'proof' of the efficacy of innovations, such as PPT, before they are prepared to invest time and money implementing them (Pannell 2003, Rodriguez et al. 2008). Until IPM practices are observed in farmers' fields, their capacity for improved pest management remains sceptical in the eyes of potential IPM users (Munyua 2003). Farmers in the Midlands North specifically requested 'proof' that push-pull could contribute to a reduction in *E. saccharina* levels in sugarcane, leading to the creation of the large-scale field trials in that region (Cockburn 2012). The field trials helped these farmers to better understand the implementation, management and spatial arrangement of PPT and its environmental and economic benefits, thereby leading to improved adoption rates of push-pull and IPM as a whole (Cockburn 2013, Conlong et al. 2016).

The poor adoption of PPT amongst KZN coastal sugarcane farmers is thought to be the result of a lack of push-pull research being done in the area. With this in mind, this study aimed to assess the efficacy of PPT, as well as the ease of its implementation, along the coastal regions of KZN using on farm field trials. These field trials will be conducted on selected model farms and will be used to test the effects of push-pull on populations of *E. saccharina*. In this chapter, the working model for the implementation of push-pull in the Midlands North region, as developed by Cockburn (2013), will be reviewed, tailored and improved to suit the management activities of coastal sugarcane farmers. The information gathered, will be used to help farmers make more informed decisions and potentially offset any worries regarding the perceived risk of adopting IPM technologies with a push-pull component.

2.2. Materials and Methods

Methodology for this research will be closely follow that of Cockburn (2013), so that the results were comparable, and to improve the knowledge base for the facilitation of push-pull into other South African sugarcane production regions.

2.2.1. Study Site

Five Farms from two coastal sugarcane growing regions were selected as sites for on farm push-pull trials. These were the North Coast and South Coast regions. They were selected because of their high levels of *E. saccharina*, and because each region had different wards or ecozones where the efficacy of push-pull could be tested. The SASRI extensions specialists in each of these regions also expressed a willingness to promote AW-IPM and push-pull practices in their areas in a bid to combat increasing *E. saccharina* numbers.

Two commercial farms were selected from the North Coast region and three from the South Coast region. The farms that were selected were located in different ecozones or wards, which are characterized by soil substrata, annual rainfall, altitude and proximity to the coast. This was done to ensure that the results reflect the efficacy of push-pull (as a component of AW-IPM) on a wide range of coastal farms, so as to gain a better understanding of the implementation of PPT in these areas at a large-scale farm level. Sites on farms were also selected for suitability of topography, as fields needed to contain contour banks that could be used to plant *M. minutiflora*, acting as the ‘push’ component in the push-pull trials. These contours also needed to run parallel to a wetland area, which could be rehabilitated into a ‘pull site’ by replanting wetland sedges such as *C. papyrus* and *C. dives* into them. All the farms that were selected had historically high *E. saccharina* levels or are at a high risk of developing future *E. saccharina* infestations. This was confirmed by speaking to the host farmers and extension staff and by referring to LPD&VCC data from the area. Finally, it was important to select farms, whose owners or managers were co-operative and committed to the implementation of push-pull as part of an AW-IPM programme to ensure that the study could run smoothly and to ensure that trial fields were correctly maintained. Farmers had to be willing to give up time and provide labour and equipment to prepare and manage the sites, as well as ensure that the Molasses grass and *Bt*-Maize were planted, watered and supplied with any necessary fertilizers or herbicides.

The farms chosen for field trials are listed in Table 2.1 below. Figure 2.1 and Figure 2.2 show the position of the farms within the North Coast and South Coast sugarcane growing regions.

Table 2.1. Characteristics of farms and fields chosen for push-pull trial sites in the North and South Coast of KZN

	Kahlamba Estate	Evelyn Park	Glen Rosa	Sezela MCP	Ellingham Estate
GPS co-ordinates	29°16'16.4"S 31°19'34.3"E	29°24'32.5"S 31°02'22.7"E	30°17'53.5"S 30°30'08.2"E	30°24'51.6"S 30°39'21.8"E	30°19'33.6"S 30°42'20.3"E
Region	North Coast	North Coast	South Coast	South Coast	South Coast
Fields used in study	B21, B23	CE15, CE13, CE11	2, 7A	41, 42	28, 53
Push-pull field Size	13.8 ha	14.6 ha	10 ha	10.4 ha	12.8 ha
Soil types	Natal-Group Sandstone	Oakleaf, Swartland	Glen Rosa, Clovelly	Glen Rosa	Glen Rosa, Cartref, Granite
Sugarcane varieties	N29, N12	N37	N12	N12	N12, N21, N39
Suitability of topography	Very Good	Excellent	Good	Very Good	Excellent
Eldana risk category	Very high	Very high	High	Very high	Very high
Farmer co-operation	Very Good	Very Good	Very Good	Very Good	Very Good

2.2.2. Layout and preparation of trial sites

The five selected farms were identified and visited in February and March 2014 to plan the layout of the trial areas, this was done together with the farmers and extension officers. On each farm, a push-pull treatment and a control area (an area with no push-pull planned) were designated, with each area including a wetland. The treatment and control sites at each farm had to contain sugarcane of a similar age, variety and ratoon cycle. Ratoon cycle refers to the growing of sugarcane from the stubble of the previous crop without having to replant. Efforts were also made to ensure that each area was along the same water course, that they had similar topographical characteristics (such as slope and aspect) and that they were approximately the same size. Evelyn Park had two additional sites added to the trial. An extra push-pull treatment site was added, as well as another site where treatments of the

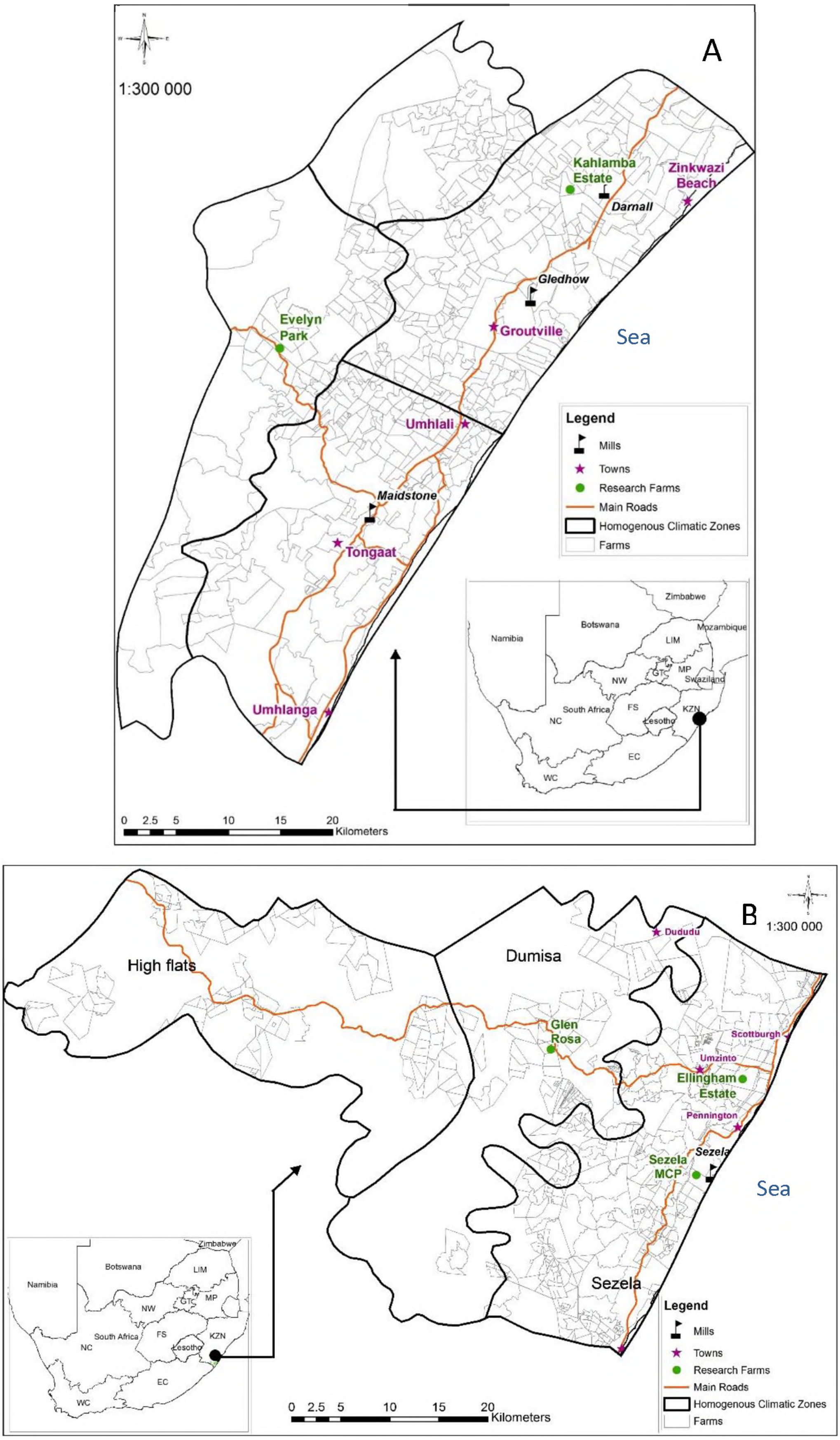


Figure 2.1. Map of the North Coast (A) and South Coast (B) sugarcane growing regions of KZN, with push-pull trial/research farms indicated in green: Evelyn Park and Kahlamba Estate on the North Coast; Glen Rosa, Sezela MCP and Ellingham Estate on the South Coast.

insecticide Fastac® were applied to the sugarcane. The sucrose content of sugarcane improves with age, with the optimum age being 18-24 months (Rostron 1972). Farmers often use Fastac® on selected fields, so that they can grow the sugarcane for longer in order to capitalise on the higher sucrose levels, without having to worry about increased populations of *E. saccharina* (as discussed in Chapter 1). The farmer at Evelyn Estate was interested in seeing how well the push-pull sites performed when compared to fields that had been sprayed with Fastac®. The layout of the push-pull trials at each site is depicted in Figure 2.2.

In June, July and August 2014 *M. minutiflora* seedlings were delivered to the farmers for planting at the treatment sites. The seedlings were purchased at Top Crop nursery (address: Brigadoon farm, Crammond, 3220; email: topcrop@superlawn.co.za) and were delivered in trays of 240 cells. Areas where *M. minutiflora* was to be planted had been discussed and mapped out prior to delivery. Farmers had to clear the contour roads in their push-pull trial fields of all other grasses and weeds before planting *M. minutiflora.* This was done 2-4 weeks before planting to avoid competition. Hand weeding or an application of glyphosate herbicide was used to kill the weeds. Seeding rippers were then used to loosen the soil in the contour roads, by opening up a furrow in the soil, so that workers could plant the seedlings quickly and easily. Seedlings were planted along the centre of the contours, with seedlings being placed approximately one metre apart. This was done on the recommendation of farmers from the Midlands North region. This central placement allows farmers to access their contours for transport without damaging the *M. minutiflora* seedlings. Planting began during the dry winter season (June – September 2014), as such, farmers were advised to water the contours where *M. minutiflora* was growing every two to three days for the first four weeks after planting. The decision was also made to plant the *M. minutiflora* together with an absorbing agent (Grovida AQUA-STOR KM™), which was able to retain water around the seedlings until the summer rains returned. The grass at three sites (Ellingham Estate, Evelyn Park and Kahlamba Estate) had to be gapped to account for seedling mortality. Maintenance of *M. minutiflora* grass stands included hand weeding when competitive grasses became too abundant.

Unfortunately, three out of five farmers (Kahlamba Estate, Evelyn Park and Ellingham Estate) selected not to use *Bt*-maize at their sites. *Bt*-maize was considered too expensive and management intensive, especially because it was highly likely that the maize would be destroyed by wild bush pigs (*Potamochoerus larvatus*), which are prevalent on many farms along the coastal belt. Since this study was focusing on tailoring the push-pull system to suite the farmers wants and needs, the decision was made to forgo *Bt*-Maize at these sites. Two farms in the south coast region (Glen Rosa and the Sezela MCP) already had *Bt*-maize growing near the treatment sites and so were happy to continue planting

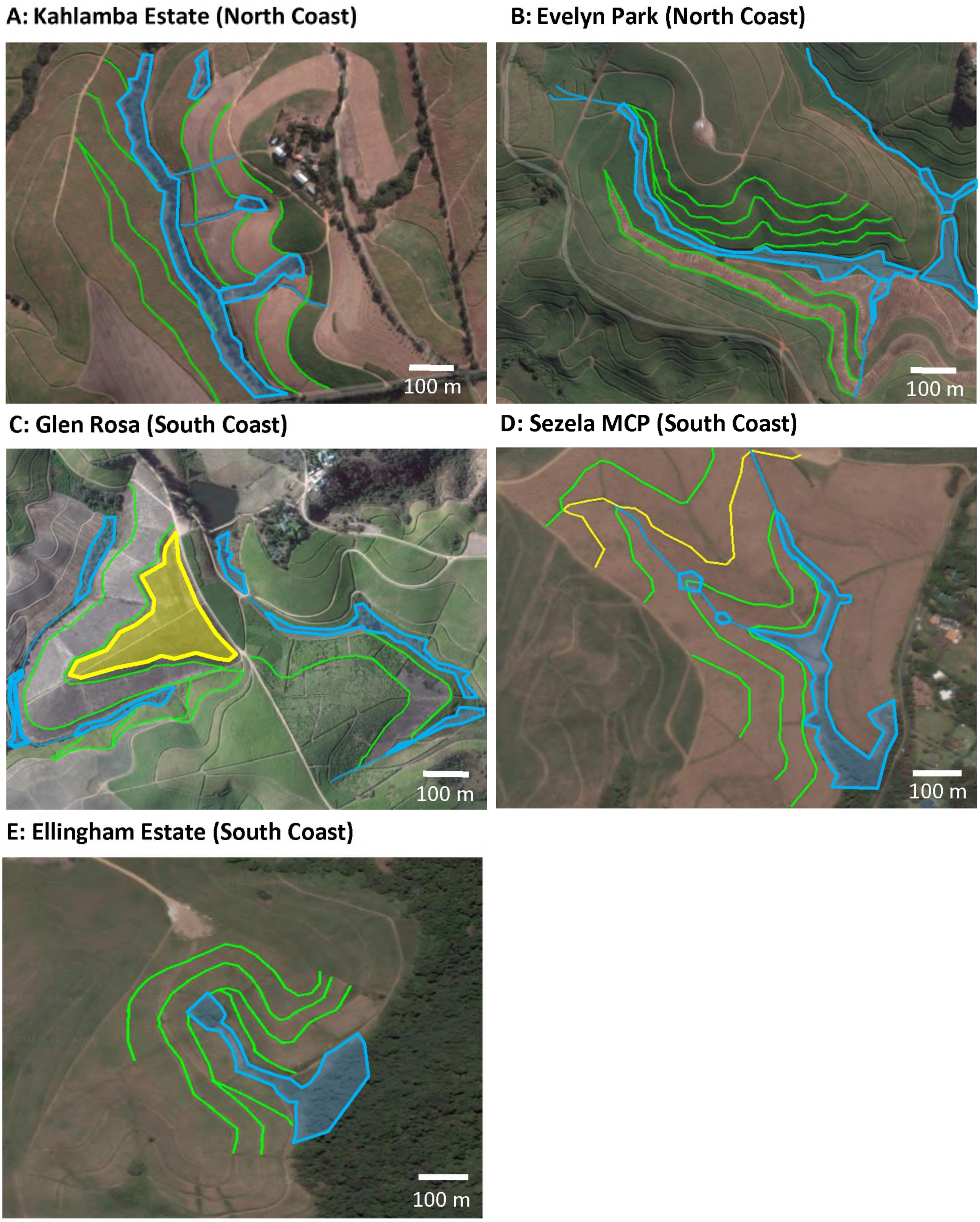


Figure 2.2. Spatial arrangement of push-pull treatment areas on trial farms. Green lines = *Melinis minutiflora*, blue areas = wetlands, yellow lines and areas = *Bt-maize* (maps not at equal scales).

it as part of the push-pull project. This created a unique opportunity whereby we could compare results and determine whether *Bt*-maize was a necessary component of push-pull systems, which already had 'pull' components in the form of wetlands rehabilitated with indigenous host plants of *E. saccharina*.

Bt-maize at the Sezela MCP Farm was planted in a single row along one contour bank three sugarcane fields away from the wetland area. Maize was planted about 3 months before the August/ September 2015 *E. saccharina* moth peak. Seeds were planted 30 cm apart along the entire length of the contour bank. Planting was done by hand and seedlings were watered for the first four weeks of growth to ensure establishment. At Glen Rosa farm, the farmer decided to convert an entire field opposite the push-pull trial to *Bt*-maize. The new maize field then acted as the 'pull' area for the trial in conjunction with the wetland habitat.

The wetlands/ water courses at each of the push-pull sites were rehabilitated by removing any of the sugarcane and many invasive plants growing in them. Some farms (Evelyn Park, Kahlamba Estates and Glen Rosa) had wetland sedges already growing in their wetland areas or on other parts of the farm. Sections of these Sedges were transplanted to the push-pull sites. Additional pull plants, namely *C. papyrus* and *C. dives,* were later bought from the Midlands North area and planted at the remaining two sites (Sezela MCP and Ellingham). Any remaining plants were distributed between Evelyn Park, Kahlamba Estates and Glen Rosa in an effort to augment their already existing sedge populations.

2.2.3. Assessment of *Eldana saccharina* infestation and damage

Surveys for *E. saccharina* infestation and damage were completed in the treatment and control experimental sites of the five model farms with the help of LPD&VCC teams from SASRI. Surveys were carried out before the implementation of the push-pull and again when the sites were harvested.

Eldana saccharina prefers to attack older, stressed sugarcane plants (Girling 1978, Way and Goebel 2003). Due to high levels of *E. saccharina*, sugarcane in the coastal regions is typically harvested at 12-15 months instead of the recommended 18-24 months (Rostron 1972). Taking into account the age of the sugarcane grown at the coast, moth peaks and harvesting times, it was decided that the control, treatment and the additional Fastac® sites (at Evelyn Park) would only be surveyed twice each. The sugarcane was surveyed once, before the study commenced, in September, October and November 2014, after which the fields were harvested. The trials were then set up and the sugarcane was allowed to ratoon and grow as per the farmers' schedule. The fields were sampled a second time, in November and December 2015. These dates ensured that the push-pull trial had been running for more than a year and that the sugarcane was able to mature, and was the right age for sampling and harvesting.

For each survey, 200 hundred stalks were randomly selected per treatment and control area on each farm. An additional four surveys were done at Evelyn Park to account for the added push-pull and Fastac® sites. The stalks were randomly chosen by walking along the contour banks and selecting ten stalks every 50 m. Five stalks were selected amongst the first three rows and another five were selected from the centre of the field/ panel. This ensured that most of the field was surveyed, and eliminated edge effect as a confounding factor. A total of 4800 stalks were sampled throughout the sampling period.

The sugarcane stalks were split along their length and inspected for stem borer damage. The total number of internodes, as well as the number of damaged internodes were counted and recorded per stalk selected (Barker et al. 2006, Cockburn 2013). The damage patterns of *E. saccharina* and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) (a minor pest of sugarcane) are very similar. Therefore, all damage typical of these two species was recorded and the data labelled as stem borer damage. This is reflected in the results. It must be noted that, as a minor pest of sugarcane, damage done by *S. calamistis* if far less frequent, extensive and destructive than *E. saccharina* (Rutherford 2015), and therefore it is predicted to have little impact on the overall distribution of the data. Any larvae found within the results were recorded and placed in labelled 30 ml plastic vials with gauze lids. The vials contained 8 ml of artificial rearing diet, the composition of which can be found in Gillespie (1993). The collected larvae were transported to the SASRI insect rearing unit and placed in a quarantine room with a controlled temperature of 28°C and a relative humidity of 75%. The larvae were monitored until the moths emerged at which point they were identified and sexed. Any parasitoids that emerged from the larvae or pupae were collected and preserved for identification at SASRI.

2.2.5. Assessment of *Melinis minutiflora* edge effect and biomass effect

To determine whether the efficiency of *M. minutiflora* in repelling *E. saccharina* moths decreased with increasing distance from the plants, an edge effect analysis was completed in November and December 2015 using damage and infestation data collected in a similar manner as discussed in the sampling procedure described in 2.2.3. The efficacy of *M. minutiflora* was ascertained by comparing the stem borer damage and infestation levels from rows on the edge of the field to rows in the centre of the field. 20 stalks were sampled per panel of sugarcane selected. 10 stalks were taken from the edge of the field, where sugarcane was growing alongside the *M. minutiflora* contours, and 10 stalks were taken from the centre of the field. This was repeated 5 times at random points at each of the push-pull sites, so that a total of 100 stalks were sampled per site. At each farm the samples were taken approximately 2 weeks after the final *E. saccharina* surveys (as described above) were completed. The Sezela MCP push-pull site was not included in this part of the study because the farmer harvested the sugarcane earlier than expected. Glen Rosa was also excluded from these tests because of the low levels of damage and stem borers found on that farm.

The percentage seedling establishment of *M. minutiflora* was also determined to assess whether the biomass of the molasses grass had any effect on stem borer damage. This was done by determining how many planted seedlings established successfully and by calculating the plant cover abundance of *M. minutiflora* stands on the contour banks (Mueller-Dombois and Ellenberg 1974, Cockburn 2013). The impact of these results were then tested against stem borer damage and infestation levels. The percentage seedling establishment was determined at the end of the sampling period (December 2015) by walking the lengths of the contour banks containing *M. minutiflora* and counting the number of plants that had established per running meter. The cover abundance was estimated using the Braun-Blanquet method for five of the contour banks planted to *M. minutiflora* per farm. In the Braun-Blanquet method the cover abundance of species (in one-meter quadrats) is estimated by a single assessor using a scale of classes, as shown in Table 2.2 (Mueller-Dombois and Ellenberg 1974, Cockburn 2013). Twenty quadrats were assessed using the Braun-Blanquet method per contour on five contour banks per farm. The mean cover abundance was then calculated by averaging the Braun-Blanquet scores for *M. minutiflora* across all quadrats in a contour bank.

Table 2.2. The Braun-Blanquet scale used to estimate the cover abundance of *Melinis minutiflora* along contour banks at the push-pull trial sites.

Braun-Blanquet Class[a]	Range of plant cover in quadrat area (%)
5	75-100%
4	50-75%
3	25-50%
2	5-25%
1	1-5%
†	<1
r	<<1

[a]Class † and r were combined in assessments and for purposes of analysis they were ignored and considered insignificant (Mueller-Dombois and Ellenberg, 1974).

2.2.4. Determining the efficacy of wetland sedges to attract *Eldana saccharina*

To verify whether ‘pull’ plants were successfully attracting gravid *E. saccharina* moths, *E. saccharina* surveys were done in the rehabilitated wetlands at each site. The transplanted sedges at each farm were sampled in November and December 2015. This was done at the same time that the final *E. saccharina* surveys were being completed in the respective push-pull trial sites. To avoid undermining the wetlands through too much destructive sampling, only 50 random plants from each ‘pull’ species (*C. dives* and *C. papyrus*) were sampled at each of the sites. The plants’ umbels, stalks and rhizomes were assessed for the presence of stem borers. The number of damaged plants per sample were recorded as well as the presence of stem borers. Stem borers were collected and transported back to the same SASRI quarantine facility as mentioned above. The insects were reared in order to confirm their species identity and any parasitoids found were preserved for identification. The levels of *E. saccharina* infestation and damage in the wetlands was compared to the levels found in sugarcane to determine whether the wetlands were successfully attracting gravid *E. saccharina* moths.

2.2.6. Statistical analysis

The percentage of stalks infested with stem borers and the percentage of internodes damaged by stem borers was calculated, as well as the number of E. *saccharina* found per 100 stalks. Data from all the trial farms were treated in this way. All the measurements that were taken are used by LPD&VCC as accurate methods to assess *E. saccharina* damage and infestations on sugarcane farms (Leslie 2009, Keeping et al. 2012). The data were checked for normal distribution before any analyses were conducted. The majority of the data collected did not have a normal distribution and therefore non-parametric statistics were used. A Pearson Chi-squared test was performed on the percentage of stalks damaged at each of the push-pull and control sites to test for significant differences ($p < 0.05$) between the sites This was also done for the mean number of *E. saccharina* found per 100 stalks at each of the treatment sites. The mean percentage of internodes bored at each of the sites was tested for significant differences ($p < 0.05$) using ANOVA. A post-hoc Mann-Whitney unmatched pairs test was used to test for significant differences between groups. The p-values were adjusted using the Bonferroni adjustment method to reduce the risks of a type 1 error (Rice 1989). Finally, a Spearman’s rank-order correlation was performed to assess the relationship between *M. minutiflora* cover abundance, and percentage plant establishment, and the percentage of internodes damaged by stem borers. All graphs and statistical analyses were generated using Microsoft Excel and Statistica v12. Tables displaying the p-values from each of the statistical tests can be viewed in the appendix.

2.3. Results

2.3.1. Assessment of *Eldana saccharina* infestation and damage

Throughout the study high levels of *E. saccharina* and damage were recorded at all sites except for Glen Rosa farm. However, *E. saccharina* numbers and levels of damaged generally decreased at push-pull sites after the field trials were conducted.

2.3.1.1. Percentage of stalks damaged per site

A significant decrease in the number of stalks damaged in the treatment plots was recorded at all of the push-pull sites except for Glen Rosa (Fig. 2.3). The highest number of stalks damaged was recorded in treatment sites 1 and 2 at Evelyn Park (Fig. 2.3. B). Before the trials were conducted the percentage of stalks damaged at these two sites were 80 % and 86 % respectively (Fig. 2.3. B). The number of damaged stalks was reduced by 49-51.3 % once the fields had been placed under push-pull management (Fig. 2.3. B). In comparison, the control site and the site that had been treated with Fastac® only showed a 2 % decrease in the number of stalks damaged (Fig. 2.3. B) However, it must be noted that while Fastac® wasn't able to significantly reduce the number of stalks damaged, it was able to maintain the number of stalks damaged at significantly lower levels than the push-pull plots (25,5 % and 23,5 %) (Fig. 2.3. B). These trends were repeated when the fields at Evelyn Park were sampled for *E. saccharina* (Fig. 2.4. B). At Kahlamba Estate the percentage of stalks damaged, after the study had been conducted, were similar at both the treatment site and the control site (Fig. 2.3. A). Whilst the final results were very similar, a comparison of each of the sites before and after the study was conducted, reveals the efficacy of PPT (Fig. 2.3. A). The percentage of stalks damaged at the push-pull site significantly decreased from 76.5 % to 54.5 %, whilst, the numbers of stalks damaged at the control site significantly increased from 30 % to 60 % (Fig. 2.3. A). Glen Rosa was the only site to show a slight increase in the number of stalks damaged in the treatment site, although this increase was not significant, unlike at the control site (Fig. 2.3. C). The number of *E. saccharina* found per 100 stalks (Fig. 2.4. C), and the percentage of internodes damaged (Fig. 2.5.2 A) also increased at the Glen Rosa push-pull site, after the trials were set up. Unfortunately, the data set for Glen Rosa was not complete. A run-away fire occurred before the study commenced and LPD&VCC data had to be used to compare the before and after results. Unlike the other model farms, Ellingham Estate showed a significant decrease in the number of stalks damaged at both the push-pull and the control site (Fig 2.3. E).

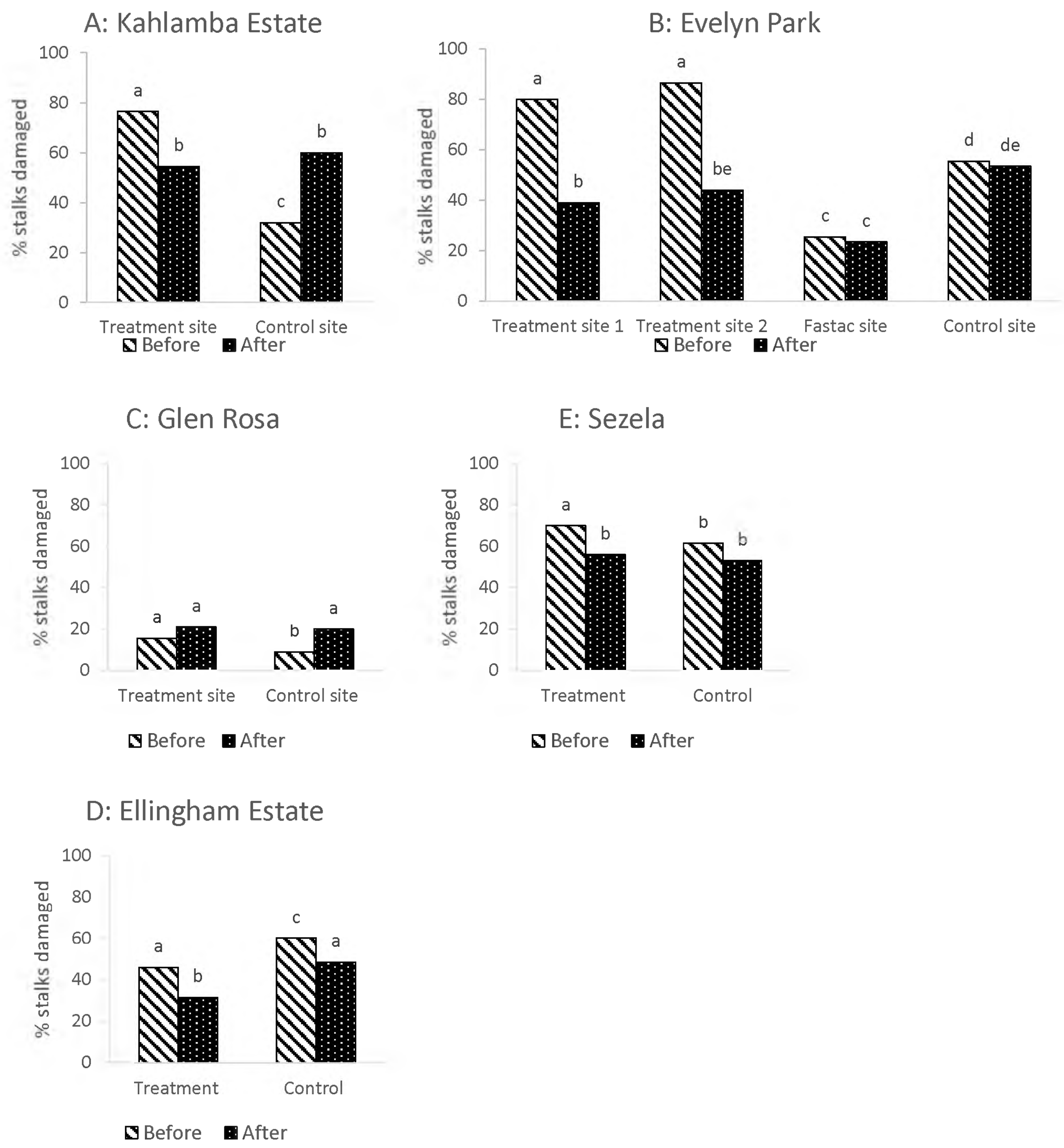


Figure 2.3. Percentage of stalks damaged in the treatment and control sites of the push-pull trials, over the full study period on all model farms. Letters indicate significant differences (X^2, $p < 0.05$).

2.3.1.2. *Eldana saccharina* infestation levels

Low levels of the stem borer *S. calamistis* were found during the sampling period (less than 2 borers per 100 stalks per site). This pest is of low economic concern in sugarcane and can be said to have a negligible effect on these farms, especially when found in such low numbers (Carnegie 1974). Therefore, only *E. saccharina* numbers are depicted in Figure 2.4. Notable reductions in the numbers of *E. saccharina* larvae found per 100 stalks can be seen in the majority of push-pull treated sites (Fig. 2.4.). *Eldana saccharina* infestations decreased by more than 50% at both the Evelyn Park and

Ellingham Estate push-pull sites (Fig. 2.4 B & E). Control sites showed little to no difference in *E. saccharina* numbers before and after the study was conducted (Fig. 2.4.). At Kahlamba Estate *E. saccharina* numbers actually increased from 9 E/100 stalks to 21.5 E/100 stalks at the control site towards the end of the sampling period (Fig. 2.4. A). The Sezela MCP treatment site also had significant reduction in the number of *E. saccharina* found per 100 stalks after Push-pull was implemented.

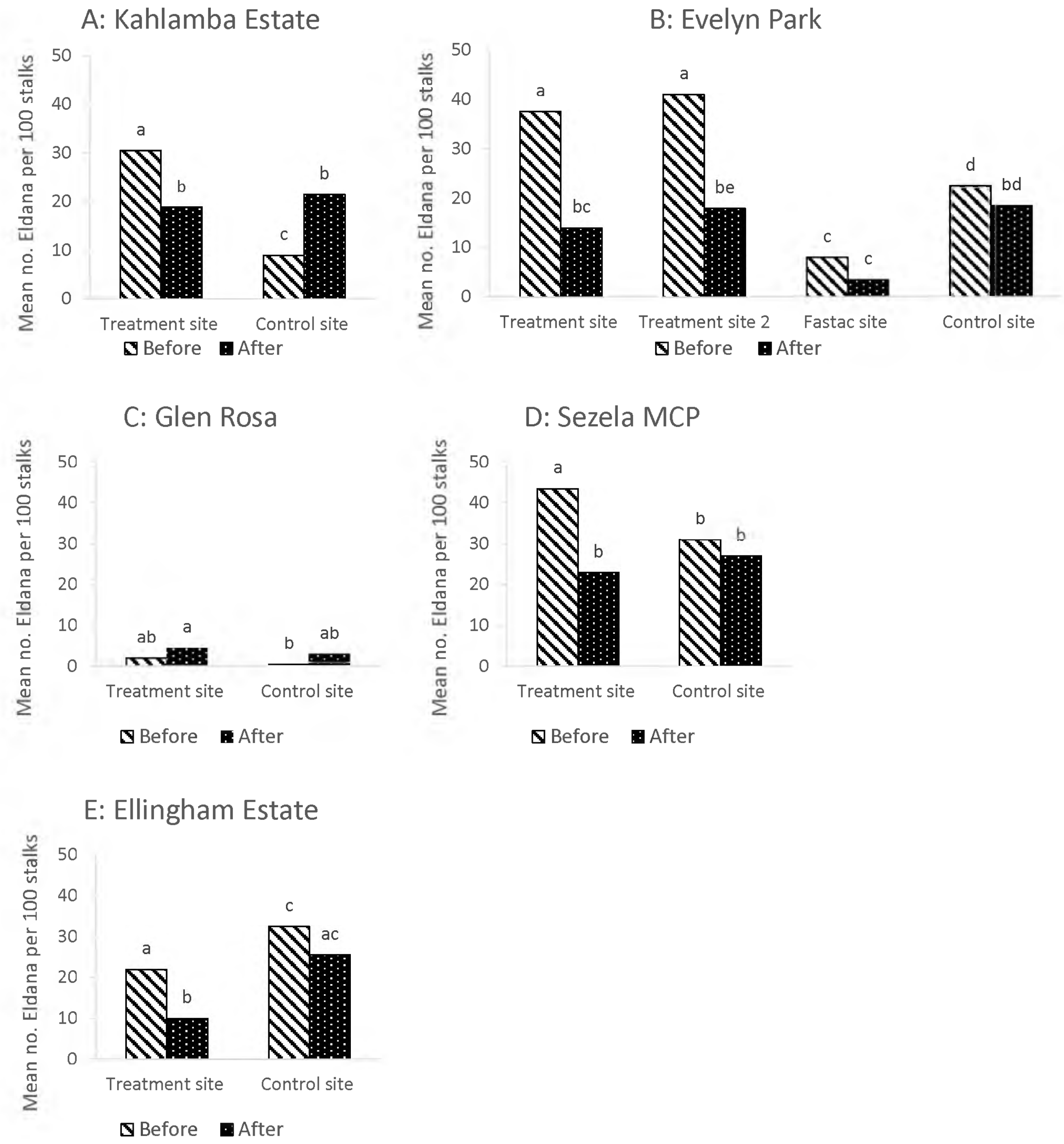


Figure 2.4. Mean *Eldana saccharina* infestation levels per 100 stalks sampled, in the treatment and control sites of the push-pull trials, over the full study period on all model farms. Letters indicate significant differences (X^2, $p < 0.05$)

2.3.1.2. Mean percentage of internodes damaged per sugarcane stalk

When compared to the graphs above (Fig. 2.3. & Fig. 2.4.), box and whisker plots depicting the percentage of internodes damaged per stalk (Fig. 2.5.1 & 2.5.2), showed similar trends at sites located in the North Coast growing regions (Kahlamba Estate and Evelyn Park) (Fig. 2.5.1.). At these sites, stem borer damage decreased significantly in the treatment sites after PPT had been implemented (Fig. 2.5.1.). At Kahlamba Estate, 15.3 % of internodes were damaged at the treatment site before PPT was implemented (Fig. 2.5.1. A). This decreased to 8.6 % after *M. minutiflora* and wetlands sedges were planted as part of the push-pull program (Fig. 2.5.1. A) Once again damage levels at the Kahlamba Estate control site increased over the study period from 6.5 % to 10.1 % (Fig. 2.5.1. A). Evelyn Park showed a dramatic reduction in the percentage of internodes damaged in the treatment sites, due to the effects of PPT (Fig. 2.5.1. B). The treatment sites showed a reduction in damage of 68 % (treatment site 1) and 67 % (treatment site 2) (Fig. 2.5.1. B). The amount of damage done per stalk was reduced from extremely high levels (16.8 % and 18.2 %) to levels that are more acceptable (5.4 % and 6 % respectively) (Fig. 2.5.1. B). The reduced levels at the end of the study at the treatment sites, while lower than that of the control site, were not significantly different from the control (Fig. 2.5.1. B). The final samples, that were collected from the Evelyn Park control site, showed that the percentage of damaged internodes was 7.2 %, slightly lower than damage recorded before the study commenced (Fig. 2.5.1. B). Once again, the field that had been treated with Fastac® maintained a consistently low level of damage (Fig. 2.5.1. B). A history of Fastac® use at this site may account for the low levels of *E. saccharina* in this field, and therefore the low levels of stalk damage at the site, at the start of the study. Interestingly, the number of damaged internodes at the push-pull sites decreased by such a large margin that PPT was able to exert a similar level of control as the chemical spray (Fig. 2.5.1. B).

The percentage of internodes damaged in the South Coast growing region (Fig. 2.5.2) was inconsistent when compared to the other measures of damage and infestation, which are depicted in Figure 2.3 and 2.4. Glen Rosa showed very little differences between the treatment and control sites before the study commenced and when it completed (Fig. 2.5.2. A). However, unlike in the graphs depicting the number of stalks damaged (Fig. 2.3. C), the number of internodes damaged was higher in the control site (2.3 %) than in treated site (2.1 %) (Fig. 2.5.2. A). Unfortunately, it is difficult to compare the before and after effects of PPT at this site because the Glen Rosa data was incomplete and the damage very low (Fig. 2.5.2. A). At Sezela MCP the percentage of damaged internodes in the treatment site was significantly lower after push-pull had been implemented, decreasing from 13.9 % to 7 % (Fig. 2.5.2. B). The control site at Sezela MCP also experienced a significant reduction, but not as large as at the treatment site, in the percentage internodes damaged per stalk from 11.8 % to 7.6 % (Fig. 2.5.2. B).

Finally, whilst the percentage of damaged internodes did decrease by 2%, from 7.7 % to 5.7 %, at Ellingham Estate, this decrease was not found to be significant (Fig. 2.5.2 C). In contrast to the trends depicted in the previous graphs, the control site at Ellingham Estate experienced a significant reduction in the amount of damage inflicted on the sugarcane stalks. However, it must be noted that the mean of final measurements taken from the control site, at 8.2 %, was still higher than either of the readings taken from the push-pull sites (Fig. 2.5.2 C). Overall, the data can be said to be highly variable with a wide distribution between undamaged stalks and stalks that had been severely damaged by *E. saccharina* larvae (Fig. 2.5.1 & Fig. 2.5.2). Sites that showed a lower mean percentage of internodes damaged per stalk generally displayed less variability, with less of a discrepancy between the minimum and maximum levels of feeding done by the borers (Fig. 2.5.1 & Fig. 2.5.2).

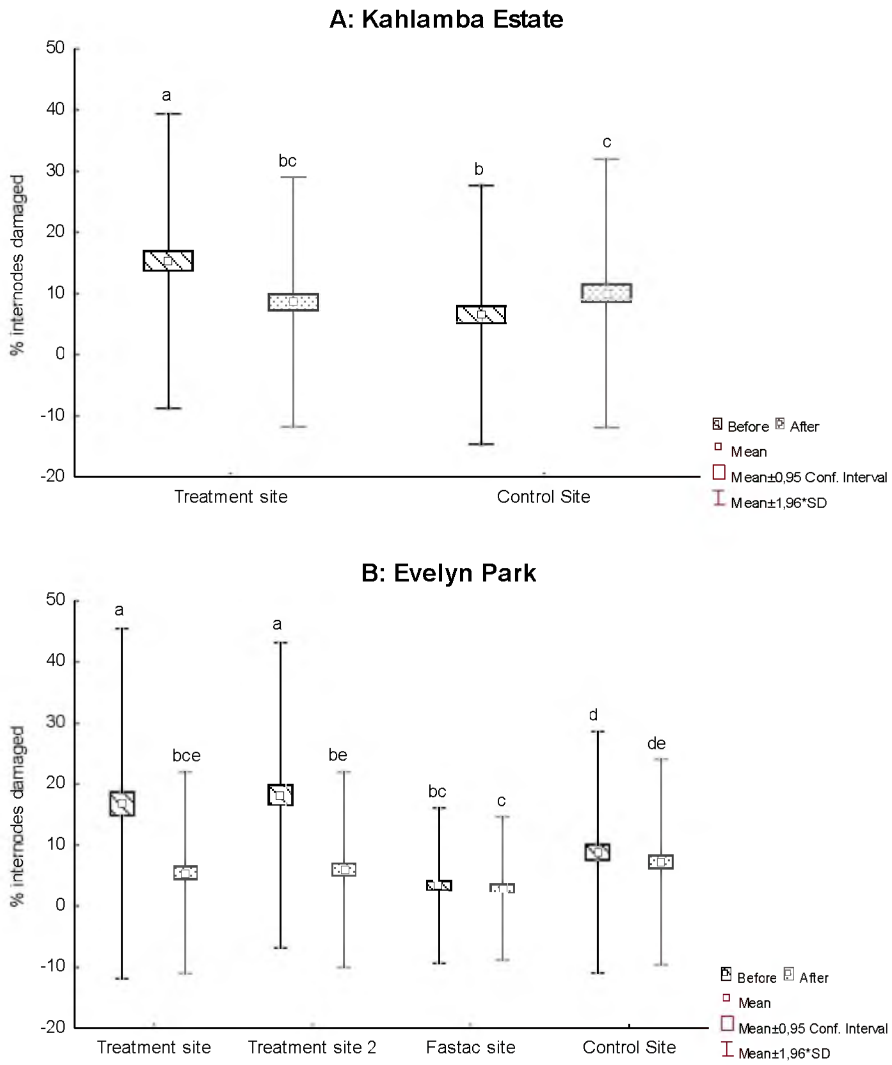


Figure 2.5.1. Box and whisker plots showing the percentage of internodes damaged in the treatment and control sites of the push-pull trials on the farms located in the North Coast growing region. Letters indicate significant differences between means (Tukey HSD, $p < 0.05$).

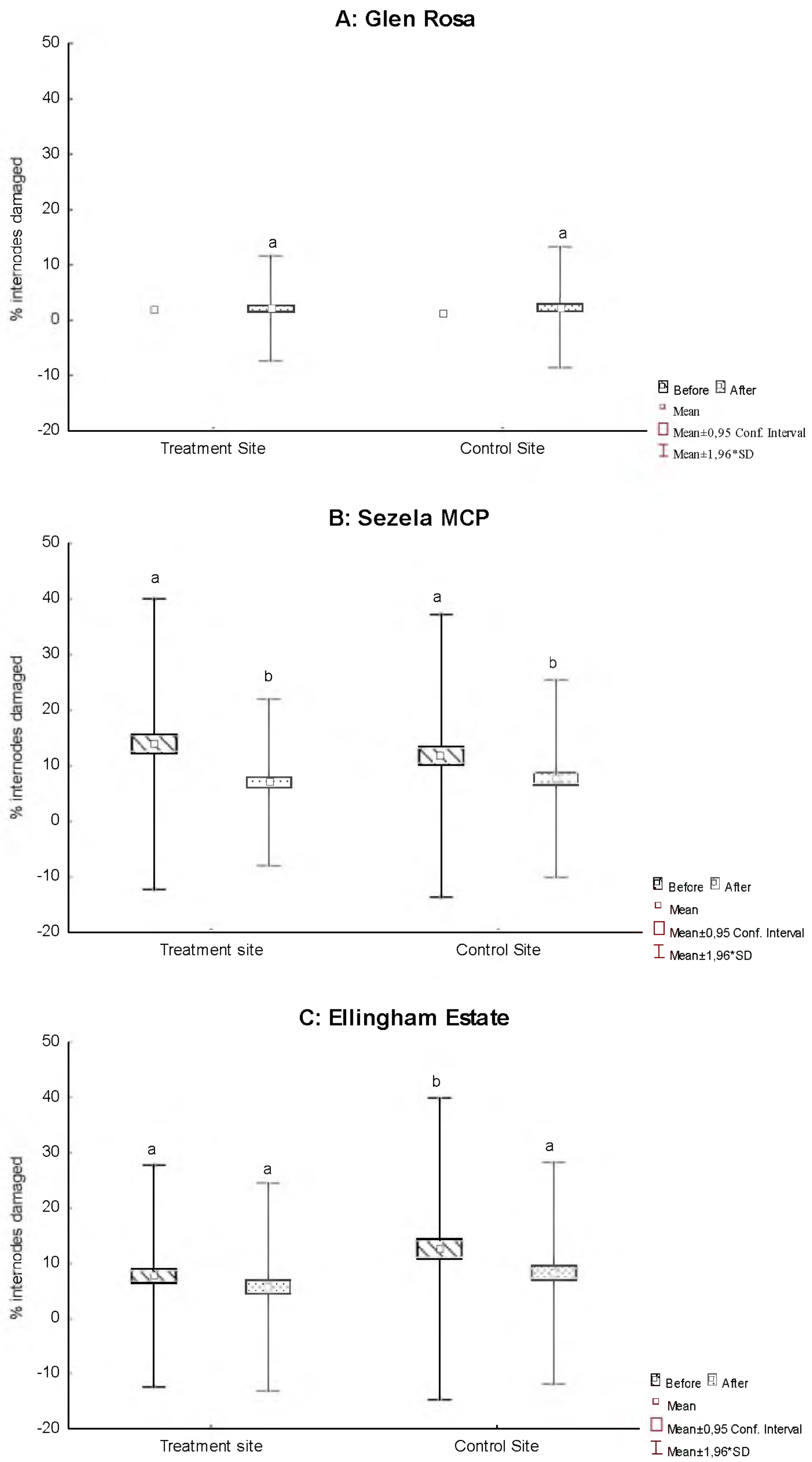


Figure 2.5.2. Box and whisker plots showing the percentage of internodes damaged in the treatment and control sites of the push-pull trials on the farms located in the South Coast growing region. Letters indicate significant differences between means (Tukey HSD, $p < 0.05$).

2.3.2. The effect that *Melinis minutiflora* has on *Eldana saccharina* damage and infestation levels.

At all the sites sampled, the amount of damage done to stalks decreased from the centre of the sugarcane fields (inner row) to the edge of the sugarcane fields (outer row) (Fig. 2.6). This means that the stalks growing closest to the contours containing *M. minutiflora* had fewer damaged internodes than those growing further away. At Kahlamba Estate and Evelyn Park the inner row of sugarcane had significantly more damaged internodes than the outer row (Fig. 2.6. A & B). The decrease in damage in the outer row of sugarcane, compared to the inner row, was not significant at Ellingham estate (Fig 2.6. C). This could be due to the fact that the Molasses grasses at this site had a lower overall cover abundance than at the other two sites (Fig. 2.8). Although the cover abundance of *M. minutiflora* at Ellingham Estate is relatively low, with a mean rank of 2.95 on the Braun-Blanquet scale, the mean percentage plant establishment of the grass at this site was high (79.8 %), however this was still lower than *M. minutiflora* establishment at the other two farms (Fig. 2.8). The mean percentage establishment of the *M. minutiflora* grass in the contours at Kahlamba Estate and Evelyn Park was also high at 90.1 % and 81.7 % respectively (Fig. 2.8). The number of *E. saccharina* larvae found per 100 stalks also increased from the outer rows to the inner rows of sugarcane (Fig. 2.7). As such, increasing distance from *M. minutiflora* negatively affects both *E. saccharina* damage and populations (Fig. 2.6 & Fig. 2.7).

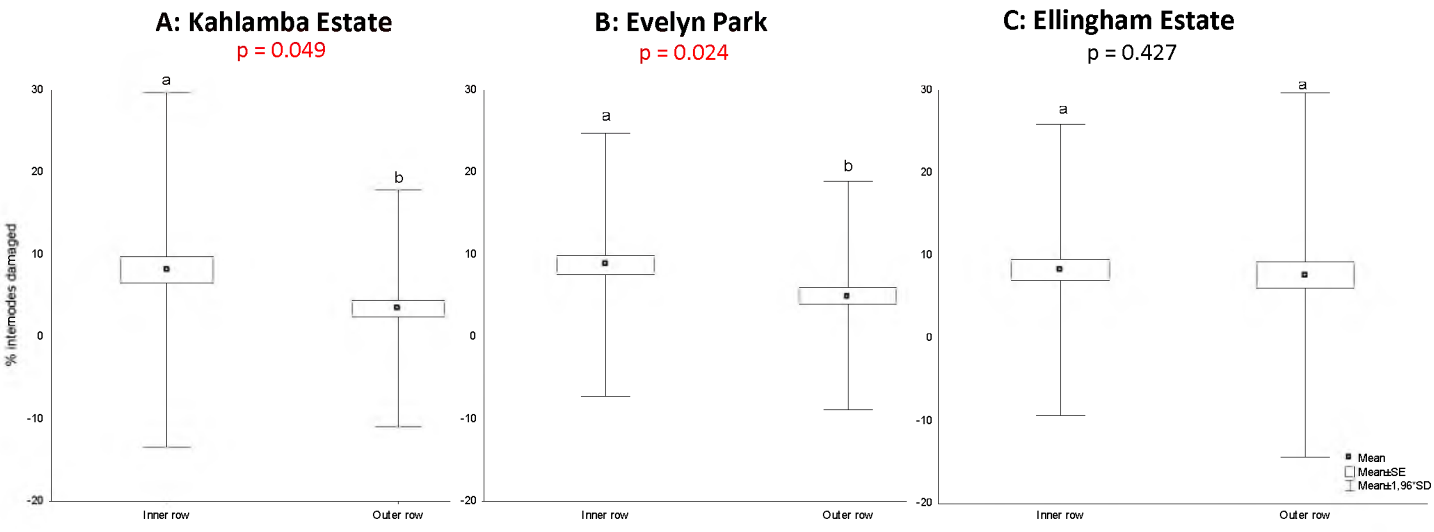


Figure 2.6. Box and whisker diagram comparing the percentage of internodes damaged at the end of the study period in the outer and inner rows of the push-pull sugarcane fields, planted with *Melinis minutiflora*, located at three of the model farms; Kahlamba Estate (A), Evelyn Park (B) and Ellingham Estate (C). Significant differences are indicated by the letters appearing above each graph.

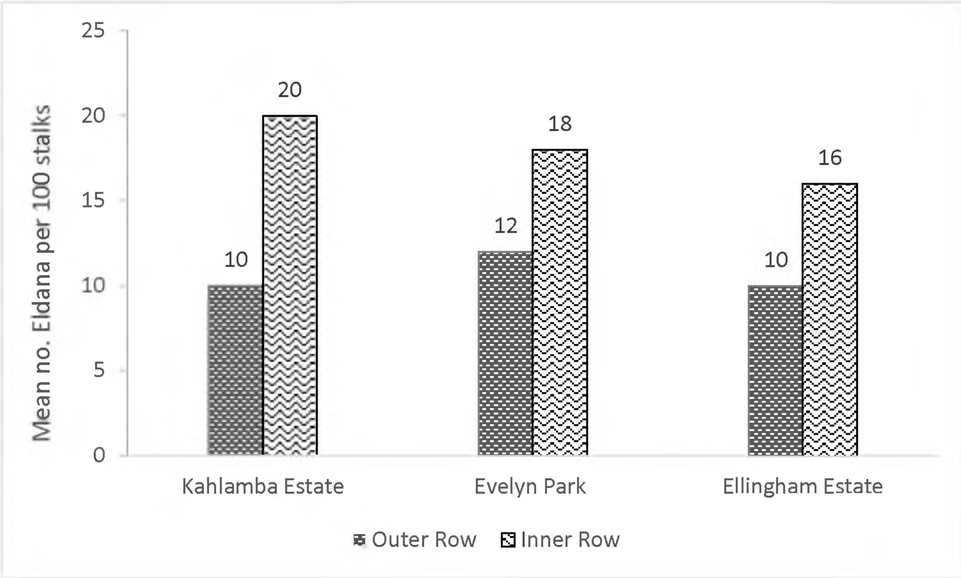


Figure 2.7. A comparison of the mean number of *Eldana saccharina* found per 100 stalks in the outer and inner rows of push-pull sugarcane fields, planted with *Melinis minutiflora,* located at three of the model farms; Kahlamba Estate, Evelyn Park and Ellingham Estate

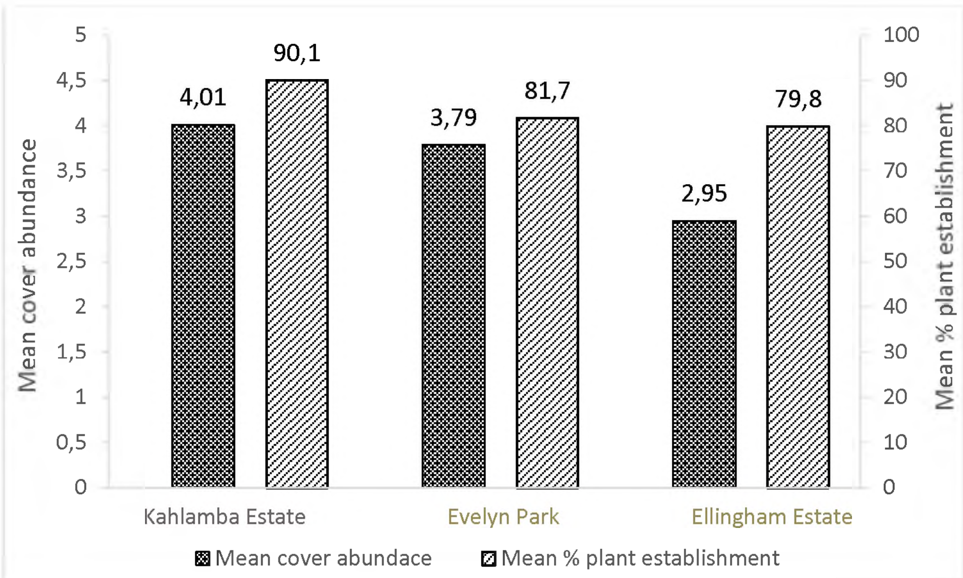


Figure 2.8. The Braun-Blanquet mean cover abundance levels (left y-axis) and % plant establishment (right y-axis) of *Melinis minutiflora* at 3 of the model farms; Kahlamba Estate, Evelyn Park and Ellingham Estate.

Mean percentage of internodes damaged is considered a more reliable estimation of *E. saccharina* infestations than percentage stalks damaged, or number of larvae found per 100 stalks (Leslie 2008). As such it was this measurement that was selected to test the relationship between *E. saccharina* infestations and *M. minutiflora* biomass. The Spearman's rank-order correlation tests whether a relationship between two variables is statistically significant by computing the test statistic R_s, which ranges in value from -1 to 1. The relationship is considered stronger if the R_s statistic is closer to -1 or 1 and weaker if it is closer to 0. The Spearman's rank order correlation testing the relationship between *M. minutiflora* plant establishment and the percentage of sugarcane internodes damaged was found to be negative at all 3 of the model farms that were sampled (Table 2.3). As *M. minutiflora* establishment increases, the percentage of internodes damage decreases at all the sites (Fig. 2.9). However, this relationship was very weak at Kahlamba Estate and Evelyn Park and insignificant p-values ($p > 0.05$) at these sites indicate that the relationship may have been generated by chance (Table 2.3). At Ellingham Estate *M. minutiflora* plant establishment had a more meaningful effect on the mean percentage of internodes damage (R_s = -0,289 and $p < 0.05$) (Table 2.3). The relationship between *M. minutiflora* cover abundance and percentage of internodes damaged is also a monotonic relationship, with damage decreasing as the cover abundance of Molasses grass increases (Fig. 2.9). The R_s values at each of the three sites indicates that the negative relationship between *M. minutiflora* cover abundance and sugarcane internode damage is weak to moderate (Table 2.3). However, the significant p-values ($p < 0.05$), that accompany the aforementioned R_s values, reveal that the association is meaningful and that there is strong evidence to suggest that the correlation is a valid one (Table 2.3). The results from Table 2.3 and Figure 2.9 indicate that *M. minutiflora* cover abundance and mean percentage internodes damaged are better correlated than *M. minutiflora* plant establishment and mean internodes damaged.

Table 2.3. Spearman's rank order correlation showing relationships between mean % internodes damaged and % plant establishment and mean cover abundance of Melinis minutiflora.

Sample:	Spearman's R_s	*p*-value
Model farm A: Kahlamba Estate:		
Mean % internodes damaged and % *M. minutiflora* plant establishment	-0,175	0,083
Mean % internodes damaged and *M. minutiflora* cover abundance	-0,382	<0,001
Model Farm B: Evelyn Park:		
Mean % internodes damaged and % *M. minutiflora* plant establishment	-0,079	0,436
Mean % internodes damaged and *M. minutiflora* cover abundance	-0,296	0,003
Model Farm E: Ellingham Estate:		
Mean % internodes damaged and % *M. minutiflora* plant establishment	-0,289	0,004
Mean % internodes damaged and *M. minutiflora* cover abundance	-0,235	0,019

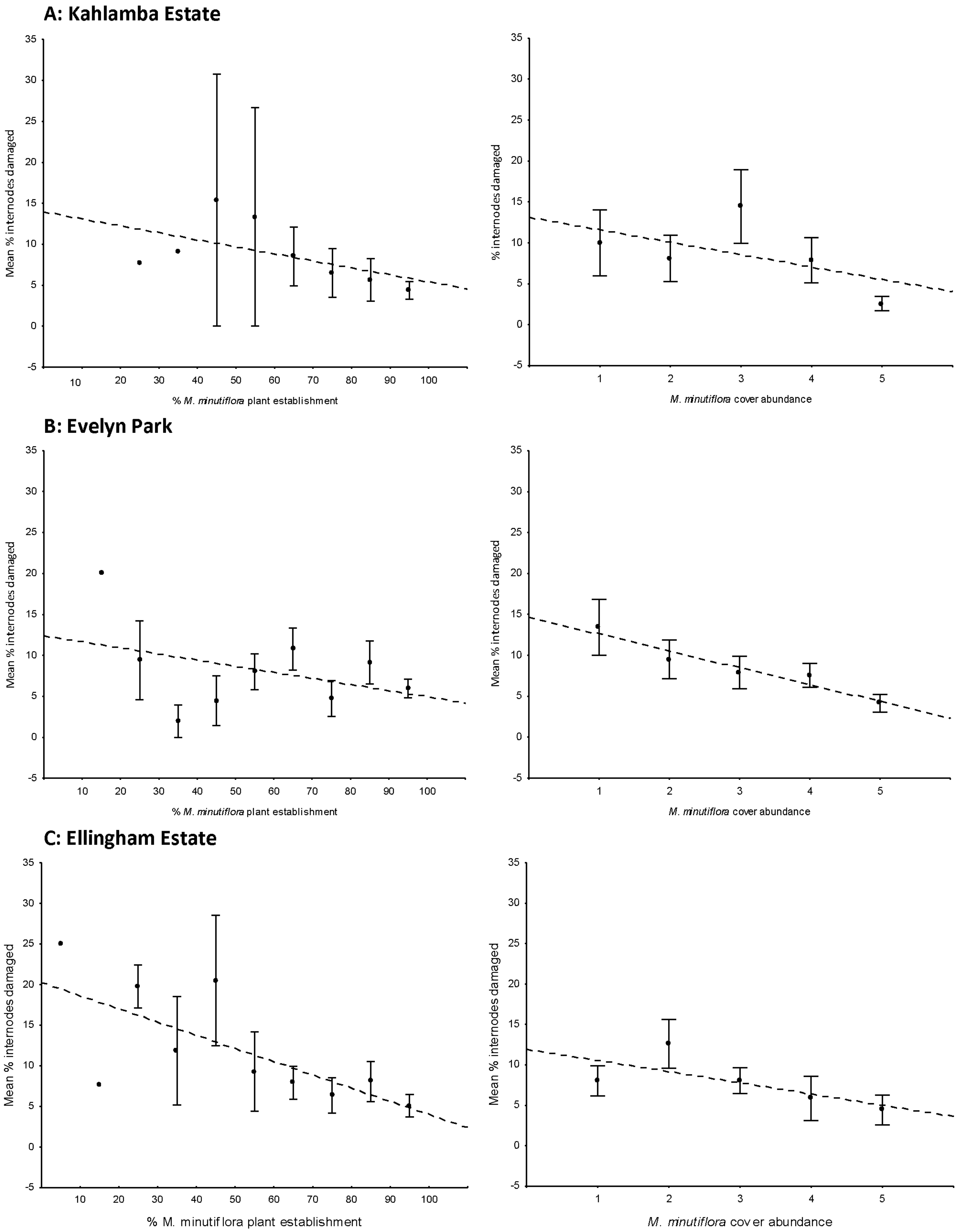


Figure 2.9. Scatter plots showing the relationship between mean % internodes damaged and % plant establishment (left) and cover abundance (right) for *Melinis minutiflora* at Kahlamba Estate (A), Evelyn Park (B) and Ellingham Estate (C). Error bars indicate ± standard error of the mean.

2.3.3. Determining the efficacy of wetland sedges to attract *Eldana saccharina*

Transplanted *C. dives* and *C. papyrus* plants were surveyed for damage and the presence of *E. saccharina* larvae at the end of the study period in November and December 2015. Sedges were recorded as damaged if either the umbel, stem or rhizome had evidence of stem borer feeding. The *C. dives* stand at Ellingham Estate had the highest percentage of sedges damaged (82 % of the sedges had stem borer damage) (Fig. 2.10). The *C. dives* plants at Ellingham Estate also had the highest levels of *E. saccharina* infestation, with 106 E recorded per 100 stalks (Fig. 2.11). This means that, on average, more than one *E. saccharina* larva was found per plant at this site. Glen Rosa had the highest percentage of plants damaged amongst the *C. papyrus* stands, with 50 % having stem borer damage (Fig. 2.10). At 40 E per 100 stalks (Fig. 2.11), the number of *E. saccharina* found in *C. papyrus* stands reflects the number plants damaged on this farm. The percentage of damaged plants and levels of *E. saccharina* in *C. dives* was also high at this farm (Fig. 2.10 & Fig. 2.11). *E. saccharina* populations and damage in wetland sedges at Glen Rosa (Fig. 2.10 & Fig. 2.11) were notably higher than the levels of the pest found in sugarcane on this farm (Fig. 2.3 & Fig. 2.4). In fact, all farms experienced high instances of plant damage and high levels of *E. saccharina* in both *C. dives* and *C. papyrus* stands (Fig. 2.10 & Fig. 2.11). The pull plant, *C. dives*, generally experienced greater levels of damage and infestation than its relative *C. papyrus* (Fig. 2.10 & Fig. 2.11). Only two sites had stands of *C. papyrus* that displayed a higher level of stem borer damage than adjacent *C. dives* plants (Fig. 2.10). These sites were located at Sezela MCP and Evelyn Park (Fig. 2.11). It is important to note that many More *E. saccharina* larvae were found in *C. dives* plants than in *C. papyrus* plants at all the sites sampled (Fig. 2.11). This may indicate that *C. dives* is a preferred host of *E. saccharina* at this time of year.

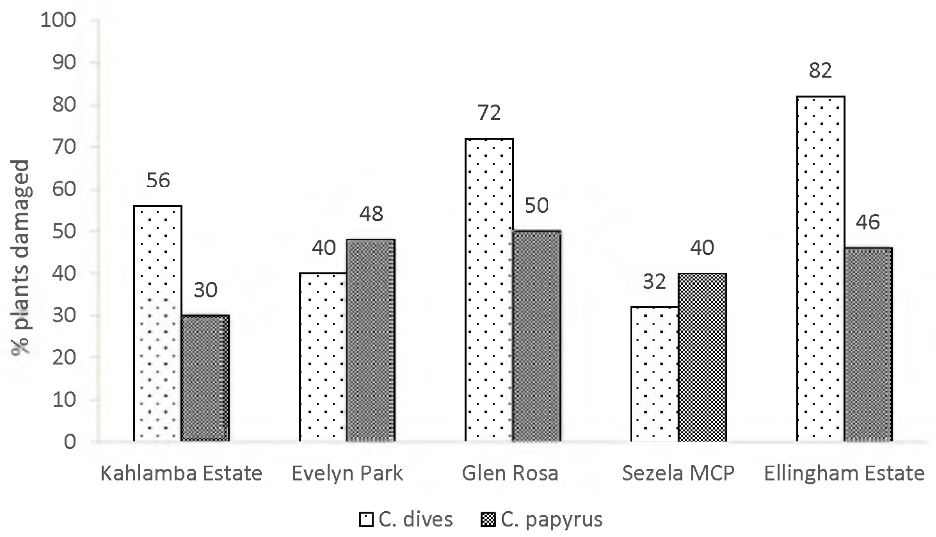


Figure 2.10. Percentage of *Cyperus dive*s and *Cyperus papyrus* plants damaged, in rehabilitated wetland areas, at each of the model farms.

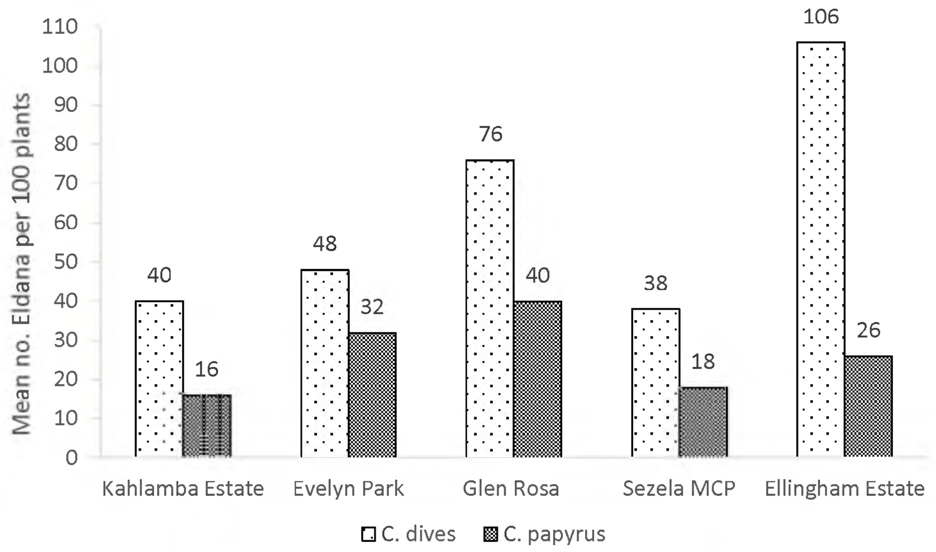


Figure 2.11. Mean *Eldana saccharina* infestation levels per 100 plants sampled, in rehabilitated wetlands areas, at each of the model farms.

In this study, eight *E. saccharina* parasitoids emerged from larvae collected from the rehabilitated water courses on the model farms. Three were discovered at Glen Rosa, Two from Evelyn Park, two from Ellingham Estate, and one from Kahlamba Estate. Unfortunately, these parasitoids could not be fully identified due to sample degradation.

2.4. Discussion

Push-pull was implemented on five model farms in two different areas of the South African sugarcane growing region. These regions were located on the North and South Coast of KZN, where *E. saccharina* numbers are typically high (Assefa et al. 2008). On the five farms, *M. minutiflora* was planted in contours to repel *E. saccharina* moths away from the sugarcane. Wetlands were rehabilitated with *C. dives* and *C. papyrus* planted to simultaneously attract the moths into their preferred ovipositional habitats. The aim of this chapter was to determine if push-pull was able to reduce populations of *E. saccharina* in the coastal sugarcane farms that were chosen as part of the study.

The influence of push-pull on *E. saccharina* populations at each of the model farms in the current study was variable. Different fields and farms have different soils, topography, water and nutrient availability, climatic factors and ratoon cycles, all of which can affect *E. saccharina* numbers and damage within sugarcane (Nuss et al. 1986). Different levels of farm management can also affect populations of *E. saccharina*, with varietal choice, sanitation practices and sugarcane age all playing a role in the level of infestation of this pest in sugarcane fields (Cockburn 2013). Because of the high level of variability within and between farms, it was necessary to compare both the before and after effects of push-pull management at the trial sites, and to compare these results to carefully monitored control sites, where no *E. saccharina* management was being implemented. This allowed us to gain a better understanding of the efficacy of push-pull on individual farms.

Although the results reported in this study are variable, all but one push-pull trial (Glen Rosa) on the selected model farms showed a significant reduction in *E. saccharina* damage and population levels (Fig. 2.3 and Fig. 2.4). This increases the evidence for the management of *E. saccharina* using push-pull, as shown by Kasl (2004), Barker (2006, 2008) and more recently Cockburn (2013). This study also demonstrates that, in addition to Pongola (Kasl 2004) and the Midlands North (Barker 2008, Cockburn 2013) sugarcane growing regions, the technology is also applicable to the North and South Coast sugarcane growing regions of KZN.

2.4.1. *Eldana saccharina* damage and population numbers on farms located in the coastal sugarcane growing regions of Kwa-Zulu Natal

To gain a better understanding of the outcomes of the push-pull trials, and to determine whether these outcomes were meaningful from a management perspective, one must first consider the economic thresholds of *E. saccharina* damage and infestation in sugarcane.

In the sugarcane industry, pest populations are carefully monitored to ensure that they do not exceed the economic threshold. The economic threshold for *E. saccharina* populations in sugarcane is approximately 10-13 E/100 stalks (number of *E. saccharina* larvae per 100 stalks) (Leslie 2009). This is the lowest population of the pest that will cause economic loss (Stern et al. 1959, Leslie 2009). Similarly, the economic injury level (EIL) for *E. saccharina* in sugarcane is 7 % stalk length red (SLR) (Goebel et al. 2005). This represents the number of internodes in the stalk that are damaged and is equivalent to yield (sucrose) loss (Goebel et al. 2005, Leslie 2009). These figures can be equated to an overall stalk damage figure of 54 % SD (stalk damage), which is the percentage of stalks that show evidence of damage by *E. saccharina* (Goebel et al. 2005). At damage levels above the threshold, the EIL has been surpassed and economic viability of the sugarcane will be seriously affected (Stern 1959, Barker 2008). For a management practice to be deemed viable it must be able to reduce or maintain *E. saccharina* numbers, and their resultant damage, to levels below these thresholds (Goebel et al. 2005).

The data presented here differs greatly to the data collected in the Midlands North by Cockburn (2013). The sites and farms that were sampled in that study had low levels of *E. saccharina* (Cockburn 2013). The highest percentage of stalks damaged in the Midlands North study was 31 % and none of the sites sampled in the Midlands North recorded more than 10 E/ 100 stalks (Cockburn 2013). These figures are below the economic threshold for *E. saccharina* in sugarcane.

The high levels of damage and infestation at many of the coastal farms was in stark contrast to the findings of Cockburn (2013). Four of the model farms in this study (Kahlamba Estate, Evelyn Park, Sezela MCP and Ellingham) had extremely high levels of stem borer damage and high numbers of *E. saccharina* per 100 stalks at the commencement of the study. The highest percentage of stalks damaged in this study was recorded at Evelyn Park, where damage levels were approximately 30 % higher than the recommended threshold (Fig. 2.3). In fact, almost all the fields sampled at the beginning of the study had damage and infestation levels that exceeded the thresholds as described in the above section. Those fields that did not exceed the threshold level were at a high risk of doing so if the sugarcane had not been harvested. This demonstrates the importance of early harvesting as an *E. saccharina* management tool in the coastal sugarcane regions of KZN. The only exceptions were the sites located on the farm at Glen Rosa. These had low numbers of *E. saccharina* (Fig. 2.4) and the damage recorded was well below the EIL (Fig. 2.3 & Fig. 2.5.2). Whilst Glen Rosa falls under the South Coast sugarcane growing region, it is located more inland, between the mist-belt and the hinterlands, where altitude, lower winter temperatures, better soil conditions and improved water availability (le Roux 1993) help to keep the *E. saccharina* numbers low (Dick 1945). This accounts for the low infestation and damage levels found at this site.

The high levels of *E. saccharina* damage and infestation at the start of the study, confirm that there is a need for alternative methods of pest control in this region. The results of this study indicate that PPT might provide coastal sugarcane farmers with an adequate solution to the *E. saccharina* problem.

2.4.2. The effects of PPT on *Eldana saccharina* infestations and damage levels in sugarcane

Push-pull was able to significantly reduce the number of stalks damaged at all the treatment sites except for the site at Glen Rosa. At Evelyn Park, the percentage of stalks damaged at both the treatment sites was decreased by to such an extent that damage fell below the threshold level of 54 % SD (Fig. 2.5. B). As described previously, economic thresholds act as decision making tool for farmers (Stern 1959). To ensure the viability of their sugarcane, farmers can either cut their sugarcane or apply insecticides to their fields if threshold levels are exceeded. The potential of PPT to reduce damage to below economic threshold levels means that farmers may be able to grow their sugarcane for a longer period of time before having to cut or spray insecticides. Since many coastal sugarcane growers choose to harvest their fields in response to high *E. saccharina* levels (chapter 3), these results mean that farmers using PPT as part of an AW-IPM program, could potentially age their fields to improve the sucrose content of the sugarcane and thereby increase profit (Rostron 1972). This would have cost implications for many coastal sugarcane farmers, who are financially constrained by having to harvest their sugarcane at 12 months, instead of the recommended 18-24 months (Bezuidenhout et al. 2002, Inman-Bamber 1991, Ramburan 2015). Although the percentage of stalks damaged at some of the control fields also decreased, this decrease was less pronounced. At Kahlamba Estate stalk damage increased significantly in the control field after the study (Fig. 2.3. A). This increase in damage may be due to the sugarcane being water stressed, as the coastal area of KZN was experiencing a drought at the time of the study (Singels et al. 2016). Therefore push-pull was not only able to significantly reduce SD at Kahlamba Estate, but the technology also prevented *E. saccharina* from taking advantage of the water stressed plants, which are usually more susceptible to infestation (Singels et al. 2016).

The efficacy of push-pull is also evident in the *E. saccharina* surveys as depicted in Figure 2.4. Most of the sites had high levels of *E. saccharina*. Three of the farms in the study had over 30 E/100 stalks at the treatment sites at the commencement of the study (Fig. 2.4) This is problematic from a pest management perspective because such numbers are highly damaging to sugarcane, and because high infestations pose a risk to nearby fields and farms, since *E. saccharina* are able to disperse into surrounding areas (Atkinson 1981). All farms, except Glen Rosa, saw a dramatic decrease in the mean number of *E. saccharina* found per 100 sugarcane stalks, after PPT had been implemented. The number of larvae found in stalks at the push-pull treatment sites at Evelyn Park and at Ellingham Estate decreased by more than 50 % (Fig. 2.4. B & E). The treatment sites at Kahlamba Estate and Sezela MCP saw reductions in infestation levels of 47.1 % and 37.7 % respectively (Fig. 2.4. A & D). In comparison to the treatment sites, the control sites experienced little to no reduction in the number of *E. saccharina* found per 100 stalks. This is in accordance with previous work, which showed similar reductions in *E. saccharina* populations in push-pull treated plots (Kasl 2004, Barker 2006, Barker 2008, Cockburn 2013). It can therefore be concluded that push-pull did have a meaningful impact on the population of the stemborer within the treated fields.

Glen Rosa was the only farm where the number of *E. saccharina* found per 100 stalks increased slightly at the push-pull site. This may due to the fact that this site had such low levels of damage and infestation that *M. minutiflora* was unable to exert much of an effect on the population of *E. saccharina* residing there. This reflects some of the data collected by Cockburn (2013) and Barker et al. (2006), who found that PPT was less effective at treatment sites that had low populations of *E. saccharina*. This indicates that PPT performs more effectively in areas that have a history of high *E. saccharina* infestation. Barker et al. (2006) demonstrated that the beneficial effects and the overall cost benefits of push-pull were greater where higher damage levels of *E. saccharina* were recorded.

Percentage stalk length red (SLR) is closely related to the percentage of internodes damaged per stalk and provides an accurate measure of the history of *E. saccharina* within a sugarcane field (Leslie 2008). This is because damage done by the stem borer is still evident within the stalk even after the larva has pupated and left plant (Leslie 2008). The North Coast push-pull trials (Kahlamba Estate and Evelyn Park) were the only selected model farms to show a significant decrease in the number of internodes damaged per stalk sampled. At Kahlamba Estate the percentage of internodes damaged at the push-pull site decreased by 43.8 %, while percentage of internodes damaged at the control site increased (Fig. 2.5.1. A). At Evelyn Park, percentage of internodes damaged decreased to below the EIL of 7 % (Fig. 2.5.1. B). This again offers evidence that PPT can provide meaningful control of *E. saccharina* in the coastal regions of KZN. However, in the South Coast, the results were more variable.

Once again, Glen Rosa produced fairly homogenous results, showing no differences between the treatment and control sites (both before and after the trials). Both the control site and the treatment site at Sezela MCP experienced a significant decrease in the percentage of internodes damaged (Fig. 2.6.2. B). This is despite the fact that the control site had high levels of damaged plants and numbers of *E. saccharina* at the end of the sampling period (Fig. 2.3. D & Fig. 2.4. D). Poor rainfall late in the 2015 season means that plants were water stressed and vulnerable stemborer attack (Singels et al. 2016). Late infestations because of the drought may have caused these discrepancies in the data. Percentage internodes damaged also decreased significantly at the control site at Ellingham Estate, without significantly decreasing at the push-pull site (2.5.2. B). Whilst the drought may have played a similar role here, it must be noted that the *M. minutiflora* at this site took a long time to establish and was accidently mowed early in the study. Thus, the push-pull system at this site did not effectively coincide with the moth peaks in April 2015 (Carnegie and Leslie 1990). There was nothing preventing oviposition at the treatment site until much later in the season, at which point PPT was working correctly and was able to curb the number of gravid *E. saccharina* moths ovipositing in the sugarcane during the second moth peak of the season in November 2015 (Carnegie and Leslie 1990) (Fig. 2.4. E). The percentage internodes damaged at the Ellingham Estate treatment site at the end of the study was lower than the EIL, therefore PPT was deemed effective at this site. However, this highlights the fact that PPT is knowledge intensive and should be timed properly so that push-pull will impact egg-laying moths, and so that vulnerable ageing sugarcane is protected correctly (Cockburn 2013). Thus, it is vital that farmers are aware of *E. saccharina* biology, so that they can coordinate the planting of push-pull plants. Push-pull plants need time to grow and mature before the *E. saccharina* moth peaks occur in April and November (Carnegie and Leslie 1990, Cockburn 2013). Kasl (2004), Barker (2008) and Cockburn (2013) stress the importance of timing the planting of push-pull plants correctly.

Despite the overall success of the project in reducing *E. saccharina* infestations, results recorded at Glen Rosa showed that *E. saccharina* increased (insignificantly) at this site. Significant reductions in pest damage at the control sites at Sezela MCP and Ellingham Estates also call into question the validity of the results produced by PPT there. Decrease in *E. saccharina* at the push-pull sites may be indicative of farm-wide reductions in pest populations at these farms. To understand if PPT is truly effective, one needs to garner a better understanding of the interaction between different chemical cues, plant-pest dynamics and the response of multiple arthropod communities to PPT in sugarcane (Eigenbrode et al. 2016). Additional research into the mechanisms of large-scale PPT can help growers consider more fully the behaviour of the target pest so that they can modify and improve PPT implementation to suite their own unique situations and so that they can effectively monitor and fine-tune PPT to increase its efficacy as a component of integrated pest management (Eigenbrode et al. 2016).

2.4.3. How does PPT compare to applications of Fastac®?

At Evelyn Park, fields where PPT had been implemented were compared to fields that had been treated with the chemical insecticide Fastac® (active ingredient: alpha-cypermethrin). This insecticide is used throughout the industry to control *E. saccharina*, however it is advisable to use Fastac® only on sugarcane which is going to be aged, when mills are closed, to improve sucrose content (Leslie 2009). This is usually necessary on coastal farms because the *E. saccharina* numbers are so high that it is difficult to age sugarcane without some form of pest management (Leslie 2003). The chemical is a broad-spectrum insecticide that has to be sprayed multiple times for it to be affective against *E. saccharina* (Leslie 2003). As such, it is likely that Fastac® has many non-target affects and that it is detrimental to the natural enemies of *E. saccharina* and other organisms (Bradbury and Coats 1989). At Evelyn Park, sugarcane plots subjected to PPT were compared to plots where Fastac® had been applied in order to assess whether push-pull could be used as a safer and cost-effective alternative pest management strategy for ageing sugarcane.

Fastac® showed the ability to maintain stalk damage at levels well below any of the other study sites (Fig 2.4. B). However, it must be noted that while Fastac® is able to maintain low levels of damage, it does not decrease the percentage of stalks damaged in any meaningful way from season to season (Fig. 2.4. B). The cryptic nature of *E. saccharina* means that a residual population typically remains in the sugarcane (Conlong 1994, Leslie and Keeping 1996), increasing the likelihood of resistance. Once the farmer stops using Fatsac®, it is probable that pest numbers would return to high levels within that sugarcane. In comparison to Fastac® push-pull was able to reduce stalk damage by a significant amount in the following season. As a long-term management option, PPT should, with minimal care, continue to impact *E. saccharina* populations indefinitely. It is important to note that Fastac® was able to keep the numbers of *E. saccharina* below the economic threshold (Fig. 2.5. B). Although PPT was able to drastically reduce E/100 stalks, the numbers of *E. saccharina* in the sugarcane still did not fall below the economic threshold at any treatment sites (Fig. 2.5. B). Unfortunately, starting populations of *E. saccharina* at the push-pull and fastac sites were different. Therefore, the experiment assessing the effectiveness of push-pull in comparison to Fastac® would need to be repeated for any definitive conclusions to be drawn. As such, Fastac® is still an advisable tool for farmers wanting to age their sugarcane. When sampling the percentage of internodes damaged at the end of the study, it was found, that the number of internodes damaged per stalk at treatment site 1 reduced to a point whereby damage was not significantly different to the amount of damage done to stalks at sites treated with Fastac® (Fig. 2.6.1. B). This demonstrates that PPT has the ability reduce damage as effectively as applications of Fastac®. These results indicate that, with efforts to ensure the maintenance and augmentation of push-pull plants, the farmer may be able to carry over the sugarcane in these fields without using broad spectrum insecticides such as Fastac®.

2.4.4. The effect that *Melinis minutiflora* has on *Eldana saccharina* damage and infestation levels

It is clear from the results that *M. minutiflora* influences *E. saccharina* in terms of both distance and overall biomass (Table 2.3). This is contrary to the results found in the Midlands North region (Cockburn 2013). In that study, no significant relationship was found between distance from *M. minutiflora* and *E. saccharina* damage, or *M. minutiflora* biomass and *E. saccharina* damage (Cockburn 2013). This may be due to low levels of the pest being found in that region and the variable levels of *M. minutiflora* establishment and cover abundance between sites (Cockburn 2013). In the Cloudhill sub-sample, a slight negative relationship can be seen between *M. minutiflora* cover abundance and plant establishment and *E. saccharina* damage (Cockburn 2013). This is more in keeping with the results found in the present study.

In Figures 2.6 and 2.7, it is evident that *E. saccharina* damage and infestation levels increase with increasing distance from *M. minutiflora*. At Kahlamba Estate and Evelyn Park there was a significant increase in the percentage of internodes damaged in sugarcane growing further away from *M. minutiflora* (Fig. 2.6. A & B). This means that *M. minutiflora* is effectively repelling the pests away from the sugarcane growing closest to the grass. Whilst this demonstrates the efficacy of *M. minutiflora*, farmers could benefit planting more Molasses grass in other areas of their farm. Barker et al. (2006) suggested that in addition to using contours to implement PPT, farmers could replace every 20^{th} row of sugarcane with a strip of *M. minutiflora*. By increasing the abundance of the grass with in the field, the farmer would be multiplying the effects of the beneficial, deterrent semio-chemicals within the agroecosystem (Barker et al. 2006). This would provide field-wide protection, so that all sugarcane in the field is under push-pull management. Molasses grass has been shown not to compete with sugarcane, therefore, such actions will not be detrimental to the crop (Barker et al. 2006). The economic benefits of planting extra rows of *M. minutiflora*, and the additional weed suppressing capabilities of the grass (Conlong and Campbell 2010), are likely to account for the loss of income resulting from the removal of any sugarcane (Barker et al. 2006).

In this study the biomass of *M. minutiflora* within the push-pull trials was high. The plant establishment and cover abundance of the grass was good at all three of the farms sampled in this section (Fig. 2.8). Even Ellingham Estate, with the lowest overall biomass, had better establishment and cover of *M. minutiflora* (Fig. 2.8) than most of the push-pull sites in the study by Cockburn (2013). Weekly watering of the grass at the beginning of the trial ensured that the plant was able to establish and grow even though the area was experiencing drought conditions. As such, watering is recommended to farmers wishing to plant this grass as part of a push-pull program in the coastal sugarcane belt. At all of the sites sampled, an increase in *M. minutiflora* biomass resulted in a decrease of *E. saccharina* damage in sugarcane (Table 2.3 & Fig. 2.9). Although the correlation was weak, the negative relationship between *M. minutiflora* cover abundance and percentage of internodes damaged was significant in all cases (Table 2.3). Therefore, it stands to reason that, once the grass has established, the cover abundance of *M. minutiflora* is more influential from a pest management perspective, than plant establishment alone. However, at Ellingham estate, where *M. minutiflora* cover abundance was lower (Fig. 2.8), percentage plant establishment did have a significant effect on the percentage of internodes damaged (Table 2.3). One can conclude that while *M. minutiflora* establishment is initially important in combatting *E. saccharina*, once the plant has successfully taken, the cover abundance and density of the grass plays a more significant role in repelling the stemborer.

2.4.5. Are push-pull sedges efficient at attracting *Eldana saccharina* away from sugarcane?

Pull plants are integral to push-pull systems and are planted within the agroecosystem to attract pests away from the crop. *Eldana saccharina* is indigenous to wetland habitats, therefore, it's natural host plants *C. papyrus* and *C. dives* were used as pull plants and planted in rehabilitated water courses on the model farms (Conlong 2001, Kasl 2004). At all the farms sampled, the levels of damage and infestation, in the push-pull sedges, were consistently high (Fig. 2.10 & 2.11). Therefore, it can be deduced from these results that the plants are effective at attracting *E. saccharina* moths and provide suitable oviposition sites for gravid females of the species. This is in concurrence with work done by Kasl (2004), which showed that *C. papyrus* and *C. dives* were the host plants most preferred by *E. saccharina* moths and larvae. In the current study damage levels were generally higher in *C. dives* (Fig. 2.10), and at all the sites more larvae were found in *C. dives* than in *C. papyrus* (Fig. 2.11). In the

Midlands North, the majority of *E. saccharina* were also found in *C. dives* (Cockburn 2013). This indicates that *C. dives* is the preferential host plant of the stem borer in these regions. However, *C. dives* only flowers in the summer, whilst *C. papyrus* flowers throughout the year (Carruthers 1997). Since *E. saccharina* usually feeds on the umbels of these plants (Conlong 1990), *C. papyrus* likely provides a consistent year-round food source for the pest. Thus, the importance of *C. papyrus* as a pull plant is evident and farmers are encouraged to plant both sedges as part of a push-pull strategy.

Some farmers are hesitant to plant sedges on their farms, for fear of creating a refuge for *E. saccharina*, which may result in future infestations (see chapter 3). The results gathered here suggest that sedges act as a sink and not a refuge. Data from Glen Rosa show that *E. saccharina* numbers in both *C. dives* and *C. papyrus* are high (Fig. 2.11). This contrasts with the data gathered from the sugarcane sites at Glen Rosa, which had low levels of *E. saccharina* infestation and damage (Fig. 2.3. C & Fig. 2.4. C). If wetland sedges acted as reservoir for *E. saccharina*, and not as a sink, then pest levels within the sugarcane would be much higher. This is particularly true at Glen Rosa, where *C. dives* has been growing naturally for several years. Previous studies have shown that there is a high level of parasitism of *E. saccharina* in indigenous hosts (Conlong 1990). In comparison to this, natural enemy abundances and levels of parasitism in sugarcane are very low (Conlong and Kasl 2001). Conlong (1990, 2000) showed that a complex parasitoids and other natural enemies (pathogens, predators, fungi and nematodes) of *E. saccharina* readily attack populations of the pest within natural host plants, such as *C. papyrus* in South Africa and other African countries. This helps to control and maintain pest levels in the wetlands and prevents them from re-infesting nearby sugarcane (Assefa et al. 2006). Eight parasitoids emerged from *E. saccharina* larvae collected during the study. This serves as confirmation that natural enemies are present and active at these sites, and that they are attacking *E. saccharina* in the wetlands. Additionally, *Melinis minutiflora* inter-cropping is known to decrease stem borer infestations in cereal crops, but it has also been shown to increase larval parasitism by their natural enemies (Khan et al. 1997a). Volatiles emitted by the grass, which repel gravid female moths, also contain components that simultaneously attract parasitoids, thereby increasing predation and parasitism within the surrounding area (Khan et al. 1997a). Conlong and Kasl (2001) found that parasitism of *E. saccharina* by the parasitoid *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae), increased in sugarcane when the plant was in the presence of *M. minutiflora*. Although only a few parasitoids emerged from larvae in the push-pull trials, it is possible that *M. minutiflora* attracted them into the habit. Parasitoid numbers could potentially increase if PPT is maintained in the area.

Good variety control, soil management and hygiene practices in sugarcane fields can help to ensure that *E. saccharina* remains in its' preferred wetland habitat (Assefa et al. 2006). farmers should also make certain that sugarcane does not encroach into these newly rehabilitated wetlands and that they carefully monitor adjacent sugarcane stands to ensure that *E. saccharina* is kept at bay (Assefa et al. 2006). Care needs to be taken especially at sites where there is an over-abundance of *E. saccharina* attacking the sedges. For instance, the *C. dives* at Ellingham Estates recorded approximately 106 E/100 stalks (Fig. 2.12). This means that, on average, more than one *E. saccharina* larva was found per *C. dives* plant at this site. To ensure that parasitoids are able to exert effective population pressures on the pest in transplanted sedges, efforts can be made to augment their populations at this site and other new push-pull sites, so that the stem borer is controlled in rehabilitated wetland habitats.

2.4.6. The use of *Bt*-maize in coastal push-pull systems

Bt-maize was planted at two of the push-pull model farms in this study, Glen Rosa and Sezela MCP. *Bt*-maize is extremely attractive to *E. saccharina* and can be used as a pull plant in areas that do not have adequate water courses to plant sedges (Keeping et al. 2007). The insecticidal toxin in *Bt*-maize, also kills any *E. saccharina* larvae that ingest the plant (Khan et al. 2000, Keeping et al. 2007). The model farmers at Kahlamba Estate, Evelyn Park and Ellingham Estate decided that *Bt*-maize was too costly and time consuming to be used as part of the push-pull trials on their farms. The efficacy of Bt-maize in push-pull systems is also relatively short lived (Cockburn 2013). The maize must be replanted repeatedly if it is to be effective over more than one moth peak (Cockburn 2013). The viability of growing maize as part of a push-pull system was called into question by both the model farmers and other large-scale farmers in the coastal sugarcane growing regions (see Chapter 3). Therefore, this study was used as an opportunity to test whether *Bt*-maize is a necessary component of PPT, or whether push-pull could succeed without it. The results at Glen Rosa and Sezela MCP, in comparison to results from the other model farms, indicate that *Bt*-maize is not an essential component of PPT. If a strong 'pull' factor is developed through the rehabilitation of wetlands, *Bt*-maize need not be planted as part of a push-pull program. However, it is still a useful tool for farmers who want to implement PPT, but who do not have suitable wet areas for *C. papyrus* and *C. dives* plants (Cockburn 2013). Farmers who want to protect the upper reaches of their farms are also advised to use *Bt*-Maize to attract *E. saccharina* away from their sugarcane (Cockburn 2013). Furthermore, a portion of the *Bt*-maize at Sezela MCP was destroyed by bush-pigs and had to be replanted. Since bush pigs are known pests of maize and other crops in KZN (Ehler-Smith 2016), farmers using *Bt*-maize as part of a push-pull programme may have to employ additional pest management strategies to safeguard the plant.

2.5 Conclusions and Recommendations

Evidence from the model farms shows that, while the results are variable, PPT is an effective tool for the management of *E. saccharina* in coastal sugarcane. The majority of the farms experienced a marked decrease in the levels of *E. saccharina* infestation and damage at push-pull sites. The results also show that *M. minutiflora*, *C. papyrus* and *C. dives* are successful push-pull plants, both repelling and attracting *E. saccharina* away from the sugarcane fields being protected. The discovery of parasitoids in *E. saccharina* larvae within the wetland sedges, demonstrates the potential benefits that PPT has on the recruitment of natural enemies. However, more can be done to conserve and augment populations of these parasitoids in the sugarcane agroecosystem to improve pest management through biological control.

These trials were only monitored over the course of one year. Although the trials did produce favourable outcomes, previous studies have shown that PPT, as long-term pest management tool, produces better results after it has been implemented and maintained for several seasons. As such, it is possible that farmers who persist with push-pull will be able to reduce pest populations, to levels below the economic threshold, with the help of further IPM control tactics and better farm management practices.

Chapter 3

Large-scale sugarcane farmers' knowledge and perceptions of *Eldana saccharina*, push-pull and IPM in the North and South Coast regions of KwaZulu-Natal, South Africa

3.1. Introduction

The sugarcane industry in South Africa is made up of approximately 22 500 registered sugarcane farmers, who produce and send sugarcane to one of the 14 sugarcane mills located in the KwaZulu-Natal and Mpumalanga provinces (SASA 2014, Eweg 2005). Of these farmers, 1383 sugarcane growers are classified as large-scale producers of sugarcane (Eweg 2005). Although large-scale sugarcane growers (LSGs) make up a relatively small proportion of the total number of registered sugarcane farmers, they produce over 80 % of the industries total crop (Eweg 2005).

During the 2000/2001 milling season, approximately 23.8 million tons of sugarcane was harvested in South Africa and sent to the mills to be crushed (BFAP 2014, Jones and Singels 2015). Since then, the sugarcane industry has experienced a major production decline (BFAP 2014). In the 2015/2016 sugarcane growing season, only 14.8 million tons of sugarcane was produced (CANEGROWERS 2016). This means that South African sugarcane production has decreased by almost 40 % in 15 years. The potential for further reductions are a serious concern for the industry (Jones and Singels 2015). Several factors are responsible for the steady decline of sugarcane being produced by the South African sugar industry (BFAP 2014). Rising input costs (transport and fertilizer costs), prolonged drought conditions, unresolved land claims, unsuccessful land reform projects, increased urbanization, unequal pricing systems and surges in pest, weed and disease incidences have all contributed to poor production outputs and farmer financial instability (van den Berg 2013, BFAP 2014). This has resulted in a drastic decrease in the total area planted under sugarcane, especially amongst small-scale sugarcane growers and mill-owned estates (BFAP 2014). In contrast to this, LSGs have been largely able to maintain the size of their sugarcane farms. In certain regions LSGs have even been able to increase the amount of land that is planted to sugarcane. However, poor sugarcane yields have prevented LSGs from capitalising on the amount of sugarcane that has been planted. It is vital that efforts are made to maximise farmer's sugarcane yields in order for the South African sugarcane industry to improve production outputs.

Research has shown that South African sugarcane yields have decreased considerably over the past 30 years (Jones and Singels 2015). Yield reductions have been particularly harsh in the coastal sugarcane growing regions of KwaZulu-Natal. Since 2001, LSGs have experienced yield reductions of more than 11 % in the Southern Coastal regions and over 20 % in the Northern Coastal regions (BFAP 2014). Poor sugarcane yields in the coastal regions can be attributed to adverse climatic conditions, where water availability is an important regulator of yield variability (Dube and Jury 2000, Bezuidenhout and Singels 2007). Coastal sugarcane is typically grown under dryland conditions, and farmers in this area rely on rainfall, instead of irrigation, to grow their sugarcane crops (Deressa et al. 2005). Unfortunately, the coastal regions of KZN have experienced below average rainfall in the past few years. Severe drought conditions were experienced in the 2010/2011 season and again in the 2014/2015 and 2015/2016 seasons (CANEGROWERS 2011, Singels et al. 2011, CANEGROWERS 2015, USDA 2016, CANEGROWERS 2016). However, the widening gaps between simulated sugarcane yields and actual yields cannot be explained by climate alone (Jones and Singels 2015). High infestations of the sugarcane borer, *E. saccharina*, in the coastal sugarcane growing regions may account for some of the yield declines in this area, particularly since infestations of this pest are aggravated by water stress in sugarcane (Singels and Jones 2015).

During periods of drought, susceptibility of sugarcane to *E. saccharina* is significantly increased (Atkinson & Nuss, 1989). Water stress increases the availability of *E. saccharina* ovipositional sites, as well as the stalk nitrogen content of sugarcane (Kvedaras et al. 2007). This not only results in higher populations of the pest, but also increases larval survival and biomass, and leads to quicker developmental times (Kvedaras et al. 2007). Despite the development of several less susceptible varieties and new insecticide chemistries, *E. saccharina* continues to be a major problem in the coastal region (BFAP 2014). Due to the injury inflicted by *E. saccharina*, and the high cost of insecticidal treatments, coastal farmers are forced to cut their sugarcane at 12 months, when the stalks are immature, instead of harvesting mature sugarcane at 14 months (BFAP 2014). This is an important factor leading to the reduction of sugarcane yields in the North Coast and South Coast of KwaZulu-Natal. When immature sugarcane is harvested, it contains more non-sucrose sugars than mature cane. As a result, coastal farmers are penalised for non-sucrose sugars, under the South African sugarcane industries recoverable value payment system, and thus receive lower income for their sugarcane. A suitable control measure for *E. saccharina* would greatly improve yields and increase grower profits in the coastal sugarcane belt.

An area-wide integrated pest management programme has been developed for *E. saccharina*, which promotes borer control using multiple pest management strategies. Conventional IPM methods such as judicious use of agro-chemicals, resistant varieties, cultural controls and field hygiene, biocontrol, crop-nutrition, and soil conservation are advocated as part of this approach. However, novel approaches, like habitat management and sterile insect technique, have also been included in this IPM programme. Habitat management, in the form of push-pull, has been particularly well received in the Midlands North sugarcane growing region of KZN. Push-pull has formed a vital part of IPM implementation in this area by emphasizing the roles that sugarcane health, agroecosystem biodiversity, conservation biological control, community engagement and long-term planning plays in the successful management of *E. saccharina* (Conlong et al. 2016). Unfortunately, the implementation and adoption of such integrated methods of pest control has been poor in the coastal sugarcane territories, even though *E. saccharina* populations are higher there. This chapter aimed to assess why farmers in the North and South Coast sugarcane regions of KZN have been slow to adopt push-pull, and other IPM practices, despite proven success in Midlands North. This study aimed to gain a better understanding of the pest knowledge of the large-scale sugarcane growers (LSGs) in the South Coast and North Coast regions to facilitate the successful implementation of push-pull and IPM.

Understanding the lack of adoption of new pest management interventions is a multi-layered and complex problem, which requires detailed information about numerous different factors (Hashemi and Damalas 2010). Unfortunately, these complexities are further clouded by the fact that farmers are usually presented with incomplete information about the problem, as well as the methods that could be used to manage it (Hashemi and Damalas 2010). Integrated pest management programmes generally do not consider the decision-making process of farmers and their specific reasons for choosing and employing pest management strategies (Hashemi and Damalas 2010). As such, practical recommendations for pest management often fail to be adopted by farmers (Hashemi and Damalas 2010). To improve the adoption of IPM interventions, one must first gain a better understanding of farmers knowledge and perception of pest management strategies, as well as gain an appreciation of the current pest control methods used by farmers. This can help to direct research, development and extension (RD&E) programmes to design more effective IPM implementation agendas, thereby not only improving the adoption of pest management strategies, but also ensuring that such strategies are well suited to the needs of individual farmers.

The following methods and objectives are closely related to work done in chapter 2 of Cockburn (2013), whose work was completed in the Midlands North region of KZN. This will allow our results to be compared and contrasted, thereby leading to a greater understanding of farmers' knowledge and perceptions of pests and pest management, and how these influence the adoption of new IPM techniques such as push-pull.

3.1.1 Objectives:

The main objectives of this chapter were to determine LSGs' knowledge and perceptions of *E. saccharina* and to understand the current pest management activities that they employed against this pest. Furthermore, efforts were made to determine LSGs' knowledge and perceptions of push-pull and IPM as a strategy for controlling *E. saccharina* and to obtain suggestions from the LSGs' about how to improve implementation of push-pull in the coastal sugarcane growing regions. The final objective was to determine what LSGs' perceive as potential barriers against the adoption of push-pull in this region. Using the above three objectives, our aim was to determine the feasibility of introducing push-pull on farms in the coastal sugarcane growing regions of KwaZulu-Natal.

3.2 Methods

3.2.1 Study area

Most of the farms on the South Coast supply sugarcane to Illovo Sugar (South Africa) Limited via the mill at Sezela (29°21'38.83"S, 30°41'13.37"E) in KZN (SASA 2011). Most farms on the North Coast supply sugarcane to Tongaat Hulett (South Africa) Limited via the mills at Maidstone (29°55'13.40"S, 31°13'03.29"E) and Darnall (29°26'94.00"S, 31°36'50.79"E), with some sugarcane being delivered to Illovo Sugar via the Gledhow co-operative partnership mill (29°36'17.48"S, 31°28'81.99"E) (SASA 2011). For maps of the study areas please see Figure 2.2 in chapter 2.

Although sugarcane is supplied by large and small-scale growers, this study focuses solely on largescale growers (See Chapter 4 for the small-scale grower study). While SASRI extension staff and the Local Pest, Disease and Variety Control Committee (LPD&VCC), and LSGs farmers, have shown commitment to the environmentally sustainable management of sugarcane in the Midlands North (Webster 2005, Webster 2009, Conlong et al. 2016), little is known about the perceptions of AW-IPM management amongst the coastal farmers. As such, the North and South Coast regions were chosen as study areas for further work on the implementation of push-pull and other IPM practices. Because *E. saccharina* is a problem in the coastal sugarcane growing regions, this work provides a good opportunity to put reactionary pest management measures in place. Many farms in the coastal regions are heavily affected by *E. saccharina* and implementation of push-pull may prove advantageous in reducing the pest to levels whereby farmers are able to mature their sugarcane and thus increase their profits (see chapter 2).

3.2.2 Survey method

Using a random stratified sampling approach (Fink, 2009), 76 LSGs were selected for survey interviews from across the North and South Coast regions. 34 were selected from the North Coast and 42 from the South Coast. Growers were chosen at random from the complete list of growers in each region. Farmers were asked their age, level of education (primary, secondary or tertiary level), years of farming experience and their land tenure (manager, owner or owner-manager of the farm). They were also asked whether they had completed the SASRI Senior Certificate Course in Sugarcane Agriculture. This is a six-week course hosted by SASRI and is a well-respected training course for sugarcane farming in South Africa (SASA, 2011). The questionnaire included open-ended and closed questions (Fink, 2009) to determine their knowledge and perceptions on the following topics:

- sugarcane production constraints
- insect pests, including *E. saccharina* and other damaging insects of sugarcane,
- pest management techniques used against insect pests, including push-pull and IPM
- preferred methods of dissemination of information on pests and pest management.

The survey design followed guidelines from Fink (2009). Closed questions were 'yes' or 'no' questions and categorical rank order scales or Likert-type ordinal scales were also used. For rank order scales, respondents were given five or more options per question, and they were asked to assign the top-ranked the number 1, and the bottom ranked option 5, 6 or 7 etc. Respondents were asked to express their opinions on specific topics in a range from 'strongly agree' to 'strongly disagree', on a Likert-type ordinal scale. Guidelines for effective survey interviews, including pre-testing of the questionnaire, were followed to ensure that reliable, quality data were collected and that correct social research ethics were followed (Babbie, 2010). Respondents were asked whether they were prepared to participate in the survey, the purpose of the survey was carefully explained, and anonymity assured. Interviews conducted in person were recorded so that the responses were captured accurately. Responses to questions were coded prior to analysis. Content analyses were completed on open-ended questions. This was done to better recognize repeating themes, which could then be quantified to determine LSGs' perceptions (Fink, 2009).

While every effort was made to conduct face to face interviews, some interviews were conducted over the phone, and 8 respondents answered the questionnaire via email. Initially 100 LSGs were contacted, however some farmers declined the invitation to participate in the study. Please note that, during each survey, farmers were provided with more information regarding IPM and push-pull before they were asked about the usefulness of the information that they receive from industry officials, and before they were asked about ways to improve the adoption of push-pull and barriers that may hinder the implementation of push-pull. This was done so that LSGs could respond to these questions with more confidence.

3.2.3 Statistical analysis

Descriptive statistics, such as frequency distributions and percentages, were used to analyse and report responses to questions (Fink, 2009). Contingency tables were used to analyse categorical data, and to determine the effect of groups. For example, the effect of respondents' level of education, their land tenure or their farm location on their responses to questions was determined in this way (Babbie, 2010). A Pearson Chi-squared test (X^2) was then used to analyse whether the data contained in the contingency table was statistically significant or not (Refer to the Appendix for a summary of all the data analysis methods used in Chapter 3). Respondents' answers to rank order scale questions were summarised using box and whisker plots indicating the mean rank score, 95 % confidence interval, and the minimum and maximum scores for each ranked item. Due to the non-parametric nature of the ranking data, a Kruskal-Wallis one-way ANOVA of ranks test was conducted to determine whether there was a significant difference between mean rank scores across all variables for a specific question. A post hoc Tukey HSD test was then used to determine differences within each of the variables. To determine effects of LSGs' personal profiles and farm characteristics on their responses to ranking questions, Mann-Whitney U tests and Kruskal-Wallis tests were performed. Significance for statistical tests was set at the 5% level unless otherwise stated.

3.3. Results

3.3.1. Respondents profiles

Of the 76 LSG's that were interviewed, three were women and the 73 were men (table 3.1). Two of the women who were interviewed were from the South Coast, and one was from the North Coast. The majority of the farmers from both regions were between the ages of 41 and 50 (Table 2.1). Collectively, of the farmers who were interviewed, 63.2 % had completed some level of tertiary education, with 47.4 % having studied agriculture at a tertiary level. A large number of farmers (80.3 %) had also completed the SASRI sugar course. The respondents had many years' experience working in the sugarcane industry, with 32.9 % of farmers having 11-20 years' experience, and some further 31.6 % of respondents having 21-30 years of experience (Table 3.1). When looked at separately, farmers from the North Coast had more experience than South Coast farmers, this is likely owing to the fact they were, on average, slightly older than the South Coast farmers (Table 3.1). The survey found that most farmers were the owners, or owner-managers, of their sugarcane farms (Table 3.1.).

Table 3.1: Profiles of Large scale sugarcane farmers from the North Coast and South Coast growing regions of KwaZulu-Natal

Characteristics	**North Coast (N=34)**		**South Coast (N=42)**		**Total (N=76)**	
Age (years)	Response frequency	Response percentage	Response frequency	Response percentage	Response frequency	Response percentage
18-30	3	8.8	4	9.5	7	9.2
31-40	4	11.8	12	28.6	16	21.1
41-50	18	52.9	14	33.3	32	42.1
51-60	7	20.6	8	19.0	15	19.7
60 +	2	5.9	4	9.5	6	7.9
Gender						
Male	33	97.1	40	95.2	73	96.1
Female	1	2.9	2	4.8	3	3.9
Sugarcane farming experience (years)						
< 5	2	5.9	3	7.1	5	6.6
5-10	5	14.7	9	21.4	14	18.4
11-20	9	26.5	16	38.1	25	32.9
21-30	13	38.2	11	26.2	24	31.6
30+	5	14.7	3	7.1	8	10.5
Land tenure						
Farm manager	5	14.7	11	26.2	16	21.1
Farm owner	12	35.3	9	21.4	21	27.6
Farm owner and manager	8	23.5	20	47.6	28	36.8
Lessee	2	5.9	1	2.4	3	3.9
Shareholder	2	5.9	2	4.8	4	5.3

3.3.2. LSG's perceptions of sugarcane constraints:

Farmers ranked seven production constraints according to their on-farm importance. These production constraints are as follows; rainfall, soil conditions, insect pest pressure, weeds, disease, frost and variety choice (Fig. 3.1). The farmers ranked rainfall as the most important production constraint with a mean rank of just below 2 (Fig. 3.1). Insect pests were considered as important as poor rainfall in terms of constraints, and the mean ranks did not differ significantly from one another (Fig. 3.1). Soil conditions were the other abiotic factor deemed important to overall sugarcane output. It was ranked by farmers as being statistically equal to insect pressure (Fig. 3.1). Weeds, disease and variety choice were all ranked statistically lower than rainfall and insect pest pressure as a production constraint, and frost was considered as having the least impact on sugarcane production on the North and South Coasts of KZN (Fig. 3.1). When asked about the most yield limiting pests or diseases on their farm, 60 % of LSGs responded that an insect was the worst pest on their crops (Figure 3.2).

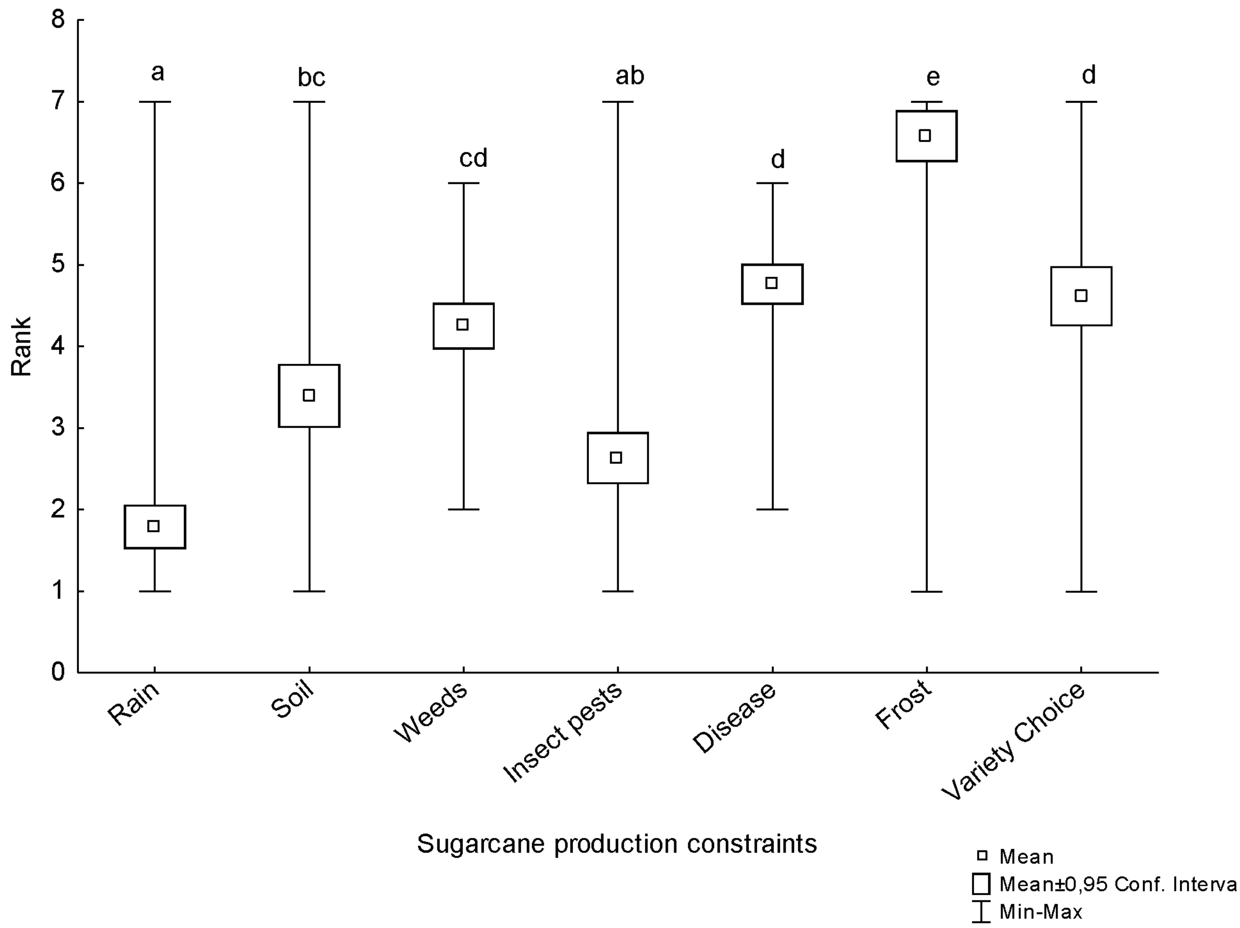


Figure 3.1. Box and whisker plot showing the mean ranked scores given by large-scale growers, with regards to what they consider their main sugarcane production constraints. Letters indicate significant differences at $p < 0.05$ (low rank score denotes the most important constraint, while a high rank score denotes the least important constraint).

Eldana saccharina was mentioned by the majority of respondents (42 %) as being the worst pest of sugarcane on their farms (Fig. 3.2). Monkeys, thrips, and aphids, were listed next as the worst animal pests on large-scale farms (Fig. 3.2.). Of the non-animal pests, weeds were considered as being a major constraint by 8 % of farmers, while diseases were mentioned less often (Fig. 3.2.). Brown rust was mentioned by 6 % of respondent, and sugarcane mosaic virus (mosaic) was mentioned by 5 % of respondents, while sugarcane smut and ratoon stunting disease (RSD) were only mentioned by 2 % and 1 % of respondents respectively (Fig. 3.2).

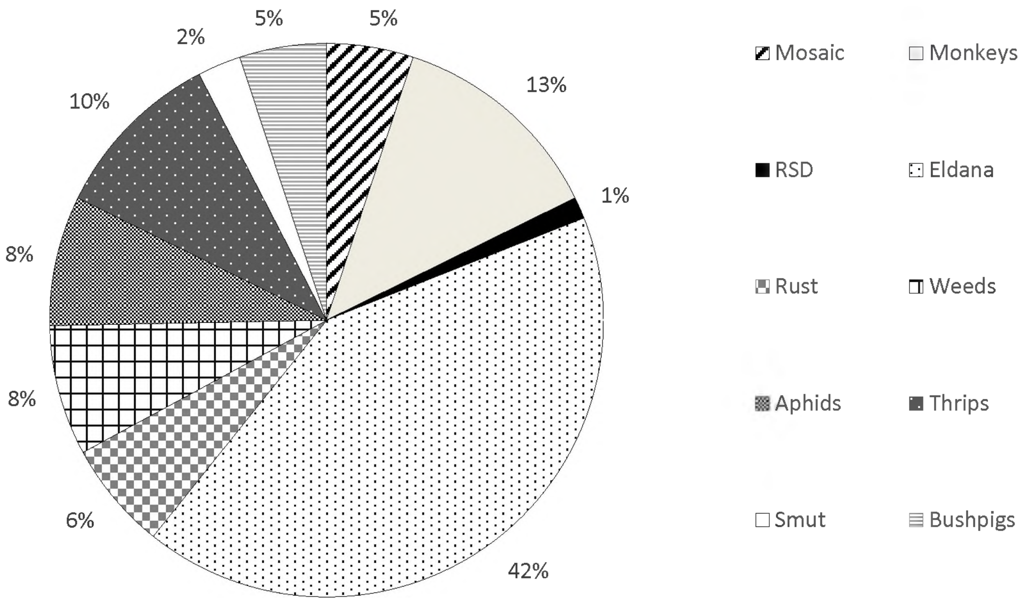


Figure 3.2. Large-scale growers' perceptions of the worst pests or diseases affecting the sugarcane production on their farms (n = 79).

When ranking the most damaging insect pests of sugarcane (from a list of 5 pests), *E. saccharina* was ranked the worst. In fact, farmers perceived *E. saccharina* to be a significantly worse constraint on their sugarcane production than any of the other insects found infesting the crop (Fig. 3.3). This indicates that LSGs regard *E. saccharina* as a very serious pest. Aphids and thrips were ranked next as being equally important to sugarcane production (Fig. 3.3). Concern about aphids and thrips was mostly expressed over two non-native pests, the yellow sugarcane aphid, *Sipha flava* Forbes (Himiptera: Aphididae), and the oriental sugarcane thrips, *Fulmekiola serrata* Kobus (Thysanoptera: Thripidae). White grubs were considered significantly less troublesome on sugarcane than all the other pests mentioned, and was given the mean lowest rank by respondents (Fig. 3.3). The level of by tertiary education of famers, age, and the location of farmers on the North or South coast, had no effect on LSGs perception of *E. saccharina* as a pest, since the majority of farmers (81.6 %), ranked *E. saccharina* as the worst insect pest.

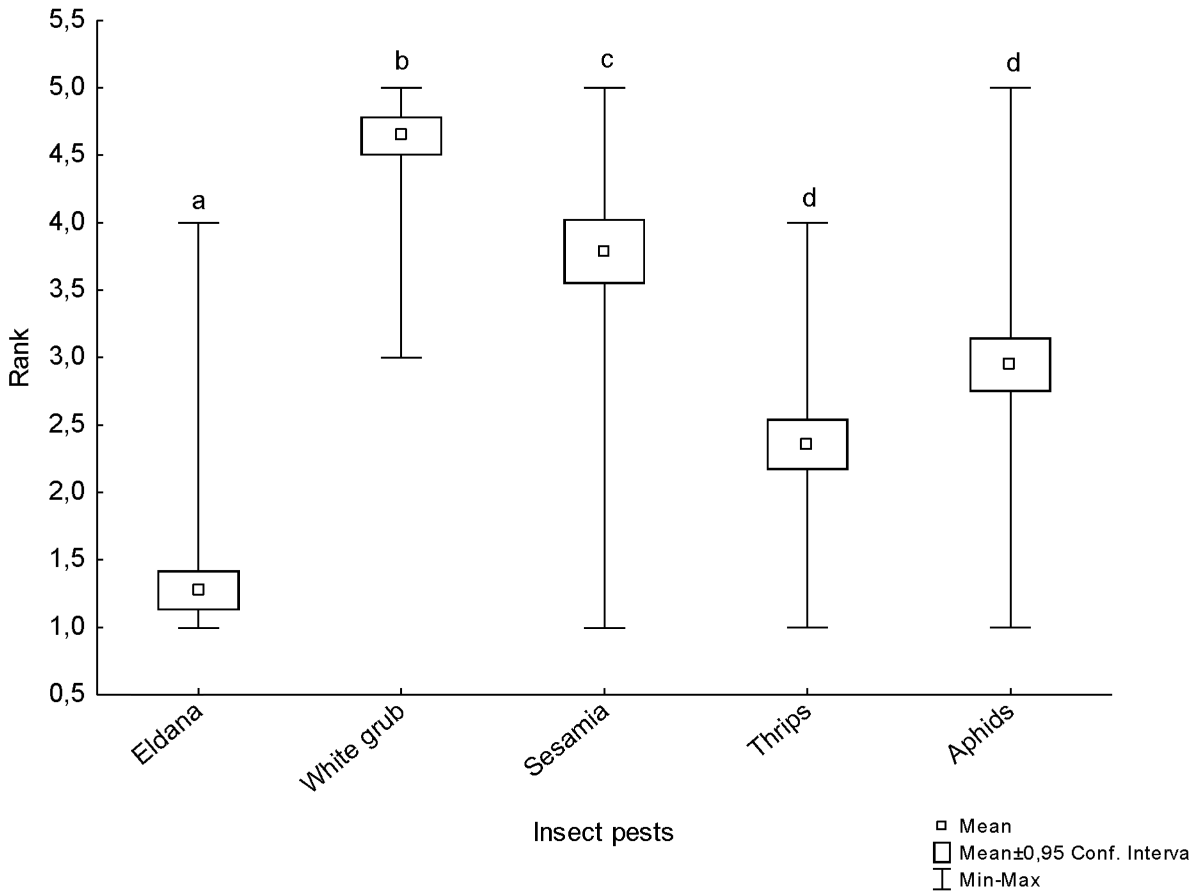


Figure 3.3. Box and whisker plot of the mean ranked scores of worst insect pests as perceived by LSGs. Letters indicate significant differences at $p < 0.05$ (low rank score denotes the most important pest, while a high rank score denotes the least important pest).

3.3.3. LSGs knowledge and perceptions of *Eldana saccharina* and the management practices used to control the pest

98.7 % of LSGs in this study confirmed that the have had infestations of *E. saccharina* in their sugarcane (Fig. 3.4). Only one farmer had no experience with *E. saccharina*, and he was located more inland than the other respondents. As such, 76.4 % of respondents were worried about *E. saccharina* affecting their yields (Fig. 3.4). However, despite having *E. saccharina* on their farms, 33.6 % of LSGs were less concerned about their yields. These farmers believe that *E. saccharina* is still relatively low on their farms compared to others, or they are confident that they are able to manage *E. saccharina* populations adequately using cultural controls, varieties, or insecticides. However, over 82 % of respondents agree that *E. saccharina* is currently a threat to sugarcane production in both the North and South coast sugarcane growing regions (Fig. 3.4). A large portion (28. 9 %) of LSGs rated the level of *E. saccharina* on their farms as high, i.e. they gave it a score of 5 out of a possible maximum of 5, with 1 representing a low level of infestation (Figure 3.4). A majority of the farmers (86.8 %) ranked the level of *E. saccharina* on their farms as a 3, 4 or 5. This means that they view their current *E.*

saccharina levels as moderate-high, with only 5.3 % of famers regarding the number of *E. saccharina* on their farms was low. Over two-thirds of LSGs were able to accurately identify *E. saccharina* borers from a photograph (Fig. 3.4). However, many lacked the ability to correctly identify the adult moth (68.4 %).

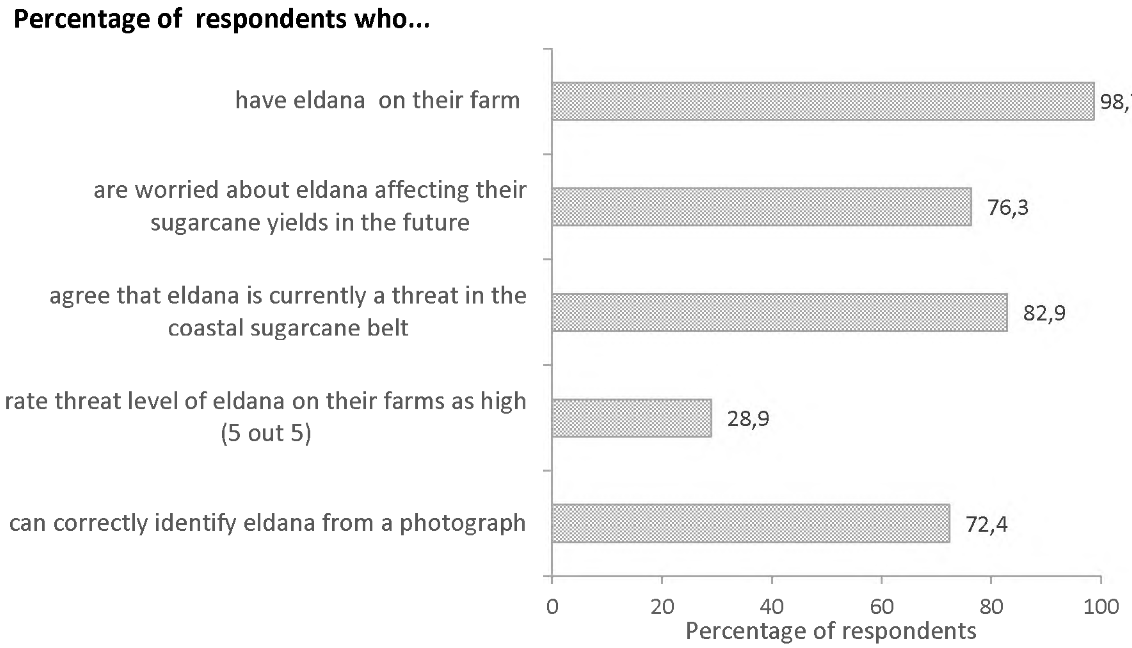


Figure 3.4. Summary of key descriptive statistics illustrating the large-scale growers' knowledge and perceptions of *Eldana saccharina* (reported as percentages of total respondents with n = 76).

Results of the ranking questions on *E. saccharina* management activities (Fig. 3.5) indicate that LSGs rely mostly on cultural controls (such as burning, early harvesting and field hygiene), as well as correct sugarcane variety selections, to manage the pest in their fields (Fig. 3.5). The least used pest management activity is push-pull, which was ranked significantly lower in terms of use ($p < 0.01$) than other management activities (Fig. 3.5). However, 8 of the 76 respondents had reported actively using some form of push-pull, such as planting sedges, or maintaining wetland areas on their farms. In contrast to data collected by Cockburn (2013) from LSGs in the Midlands North, 61.8 % of growers in the coastal areas had used insecticides to control *E. saccharina*. Despite this, insecticides were not ranked highly as a common management option (Fig. 3.5). This is because farmers only reported using insecticides if they were planning to age/carry-over their cane to improve sucrose content. The most common insecticide used was Fastac®, and 91.5 % of those who used insecticides had reportedly applied this chemical. The remaining 8.5 % of those using insecticides had only used newer chemistries such as Ampligo® (diamide-pyrethroid), Steward® (Oxadiazine) and Coragen® (diamide), with some farmers having used both Fastac® and the new chemicals. The use of monitoring as a pest management method, did not differ significantly from the use of insecticides (Fig. 3.5). This indicates that monitoring might be used by farmers to inform their decisions about whether or not to use insecticides. Note that some of the LSGs who ranked push-pull or insecticide use with a 4, did so only because they had never considered employing either tactic, and not because they had used these tools in the past.

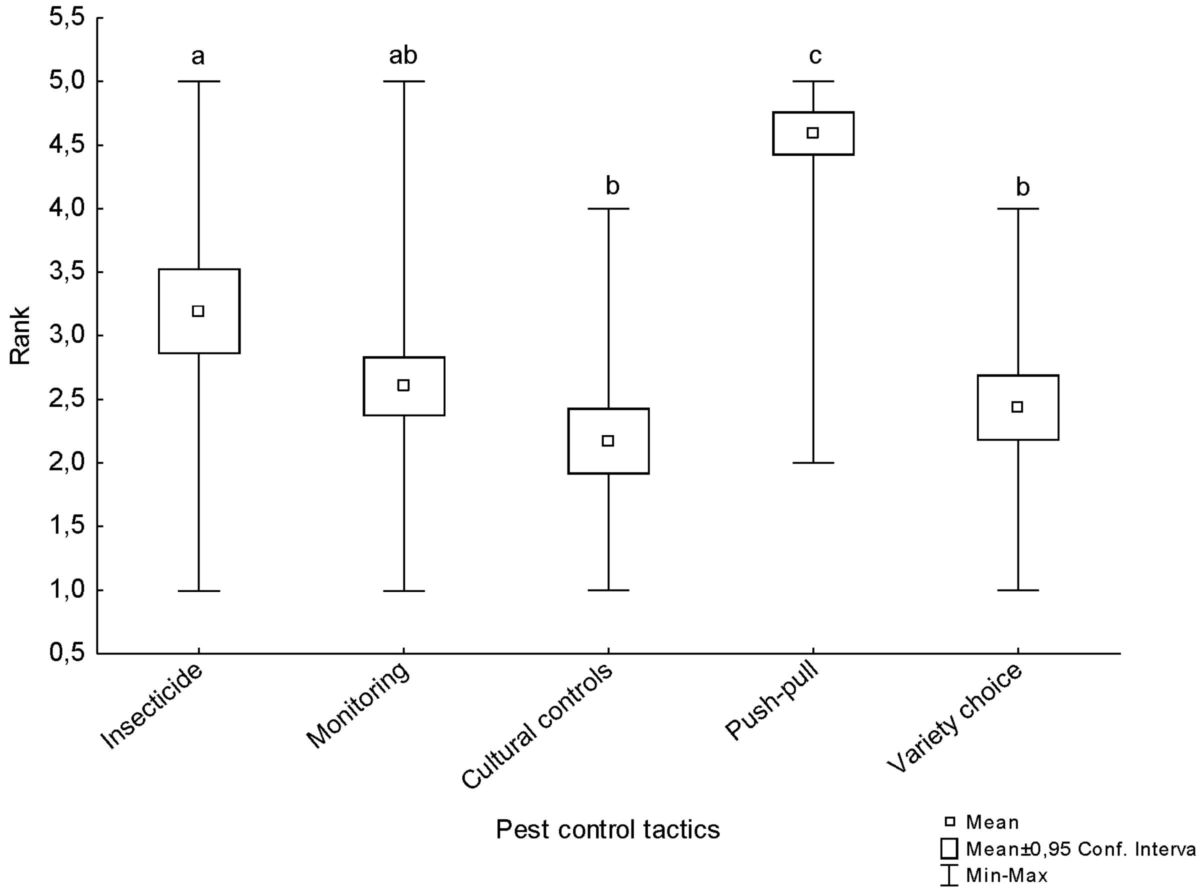


Figure 3.5. Box and whisker plot of the mean ranked scores of the *Eldana saccharina* pest management tactics used by LSGs. Letters indicate significant differences at $p < 0.05$ (low rank score denotes the most important pest management activity, while a high rank score denotes the least important pest management activity).

3.3.4 LSGs knowledge and perceptions of push-pull and IPM

LSGs in the North and South coast of KZN demonstrated good knowledge of push-pull and IPM (Table 3.2). However, of the 52 famers who had reportedly heard of IPM, 9 had not heard of push-pull as a tactic to manage *E. saccharina* populations. Therefore, only 56.6 % of all farmers had heard of push-pull specifically. The main source of information for push-pull and IPM were the information packs and brochures sent out by SASRI, followed by contact with LPD&VCC (Table 3.2). While the majority of LSGs thought that push-pull and IPM would be effective (32. 9 %), or at least potentially effective (28. 9 %), 31.6 % of growers felt that they did not understand these control strategies enough to say whether they would be useful or not (Table 3.2). This is supported by the fact that only 40.8 % of LSGs indicated that they had sufficient knowledge to implement push-pull, and only 28.9 % of farmers felt

Table 3.2. Large-scale growers' knowledge and perceptions of push-pull and IPM as shown by responses to interview questions (N=76)

LSG's questions and responses		Response frequency (N=76)	Response percentage
Have you heard about push-pull and IPM?			
	Yes	52	68.4
	No	24	31.6
Where did you first hear about push-pull and IPM?			
	LPD&VCC	14	18.4
	Other farmers	8	10.5
	SASRI Extension officers	8	10.5
	SASRI sugar course	2	2.6
	SASRI information packs or pamphlets	19	23.7
	Other	2	1.3
	None	24	31.6
Have you discussed push-pull and IPM with others?			
	Yes	42	55.3
	No	34	44.7
Discussions about push-pull and IPM were...			
	Positive	24	31.6
	Negative	1	1.3
	Both positive and negative	17	22.4
What is your opinion regarding the efficacy of push-pull for Eldana control?			
	Effective	25	32.9
	Maybe effective	22	28.9
	Not effective	5	6.6
	Don't know enough about it	24	31.6
Would you say that you know how to implement push-pull?			
	Yes	31	40.8
	No	45	59.2
Do feel that you understand the costs of push-pull?			
	Yes	22	28.9
	No	54	71.1
Would you like to learn more about push-pull?			
	Yes	65	85.5
	No	11	14.5
Would you be willing to be involved in future push-pull research			
	Yes	58	76.3
	No	18	23.7

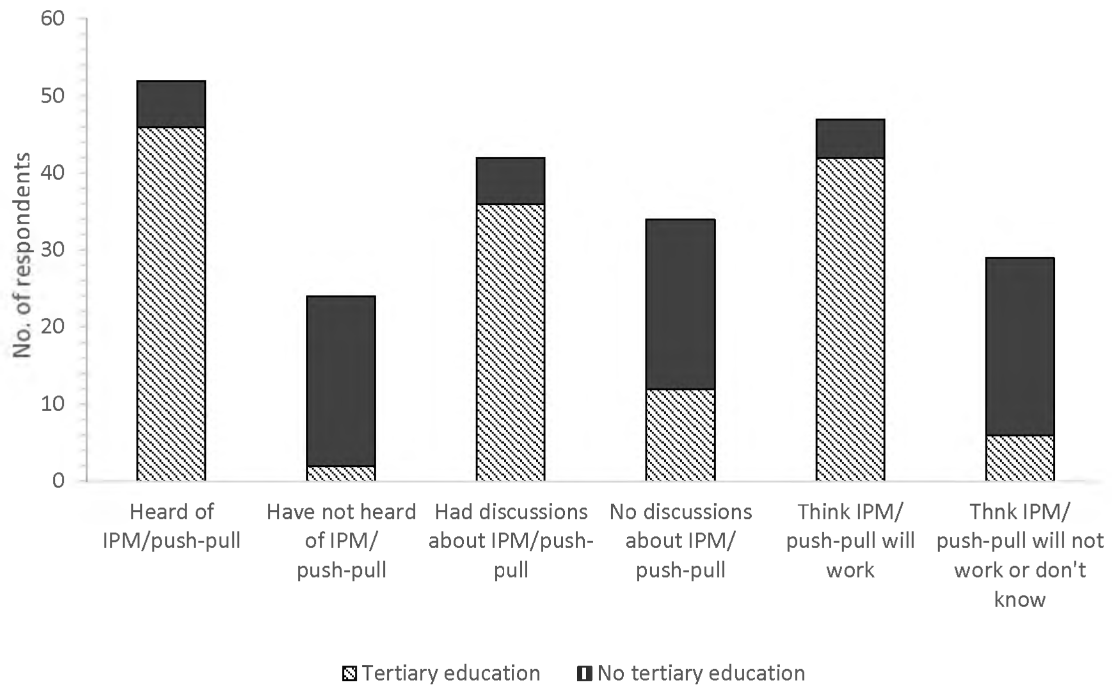


Figure 3.6. The effect that tertiary education has on LSGs knowledge and perceptions of push-pull and IPM (N=76).

that they understood the costs of implementing push-pull on their farms (Table 3.2). However, most farmers (85.5 %) did indicate that they would like to learn more about push-pull, and 76.3 % of respondents demonstrated a willingness to host push-pull field trials on their farms (Table 3.2).

Significantly more LSGs with tertiary education had heard of push-pull and IPM (Fig. 3.6, $X^2 = 45.3$, $P < 0.00$). Tertiary education also influenced whether or not respondents had discussions about push-pull with other LSGs (Fig. 3.6). Farmers with tertiary education were significantly more likely to talk to others about IPM and push-pull than those without tertiary education ($X^2 = 20.5$, $P < 0.00$), although this might be more directly related to less educated farmers not having heard of push-pull, rather than their willingness to discuss it with others (Fig. 3.6). Education level is also reflected in the perceptions of LSGs on the efficacy of push-pull. While most farmers with tertiary education (42 out of 48 respondents) thought that push-pull and IPM would be effective methods for reducing *E. saccharina* infestations, 83 % of LSGs without tertiary education felt that push-pull/IPM wouldn't work, or they felt that they knew too little about these methods to comment about how effective they would be (Fig. 3.6). Differences in LSGs perceptions of the efficacy of push-pull/IPM, in relation to different levels education, were also significant according to the chi-squared test used to analyse the data ($X^2 = 36.3$, $P < 0.00$) (Fig. 3.6).

Although most farmers had heard of push-pull (Table 3.2), and had basic knowledge of push-pull and IPM, many of the LSGs interviewed did not have an in-depth understanding of the plants used in push-pull, or where to obtain these plants. 61.8 % of respondents had heard that sedges were beneficial for controlling *E. saccharina.* However, farmers weren't always able to describe how the sedges are used, or identify them as being a part of push-pull systems. Of the 47 respondents who identified sedges as being beneficial, 40 were able to single out *C. papyrus* as potential push-pull plants. Fewer respondents (27 in total) were able to identify *C. dives* as being another important sedge in the *E. saccharina* push-pull program. Relatively few respondents had heard of *M. minutiflora* (47.4 %) and *Bt*-Maize (40.8 %) as plants used in a push-pull program. When asked about *Bt-maize*, 81.6 % of respondents said that they did not know how *Bt*-maize works. Furthermore, only 13.2 % of respondents felt that they were capable growing *Bt*-maize as part of a push-pull project. Farmers were concerned that growing maize would increase the incidence of mosaic virus in their sugarcane. Respondents also mentioned that growing maize would be a "waste of time", since pests, such as monkeys and bush pigs, would likely destroy the crop before it could provide any benefit. Others were reluctant to grow maize because they saw it as an added expense, which would not provide any profits. When pressed further, these farmers (5 out of the 76 respondents) conceded that they would indeed grow *Bt*-maize if it was proven to work i.e. if the returns outweighed the inputs needed to grow this plant as part of a push-pull initiative. LSGs in the coastal region also had poor knowledge of where to get push-pull plants. Only 27.6 % of respondents knew where to buy, or find sedges, whilst 23.7 % knew where to buy *Bt*-maize, and only 14.5 % of farmers knew where they could get *M. minutiflora*.

3.3.5 Dissemination of pest management information

100 % of LSGs agreed that the information they receive regarding pest management, from SASRI and the LPD&VCC, was useful. In contrast to LSGs from Midlands North region (Cockburn 2013), the majority of coastal farmers (85.5 %) would like to receive more information about pest management than they were already receiving from SASRI and the LPD&VCC. Only 11 out of the 76 LSGs interviewed felt satisfied with the level of pest management information provided to them. When ranking the ways that they would like to receive information, respondents ranked personal extension visits as the best form of communication when it comes to disseminating pest management tactics (Fig. 3.7). However, model farms/field days and pest management workshops were ranked equally with extension visits, in terms of significance, as preferred forms of dissemination (Fig. 3.7). Farmers commented that model farms, field days and workshops allowed them to see how well pest management works first hand, and to understand how pest management techniques can improve their yields, whilst simultaneously giving them access to extension officers or researchers, so that they can ask questions about how such tactics can be applied to their own on-farm experiences. The Kruskal-Wallis test indicated that study groups were significantly less useful to the farmers as a dissemination tool (Fig. 3.7). Although some of the respondents that were interviewed are involved in interactive groups with other farmers, they

still preferred to learn about new pest management strategies through sugarcane industry officials first. Group discussion with other farmers was considered beneficial only after information was initially gathered from extension officers and model farms etc. Pamphlets and emails were also ranked significantly lower than personal extension visits as a preferred means of dissemination (Fig. 3.7). When asked to elaborate why the farmers did not prefer reading pamphlets/emails, farmers mentioned that, while these modes of information broadcasting are useful, they are often inundated with emails and other written communications and do not always read them fully. Furthermore, LSGs commented that one-on-one discussions with extension personnel, LPD&VCC officers and researchers allows them to get a better idea about of how pest management practices can be used on their own farms. This type of information is considered to be more applicable than the generalized information received in pamphlets and emails. Results from this section indicate that, when it comes to pest management dissemination, LSGs prefer direct contact with industry officials and hands on demonstrations as opposed to written materials and discussions amongst themselves.

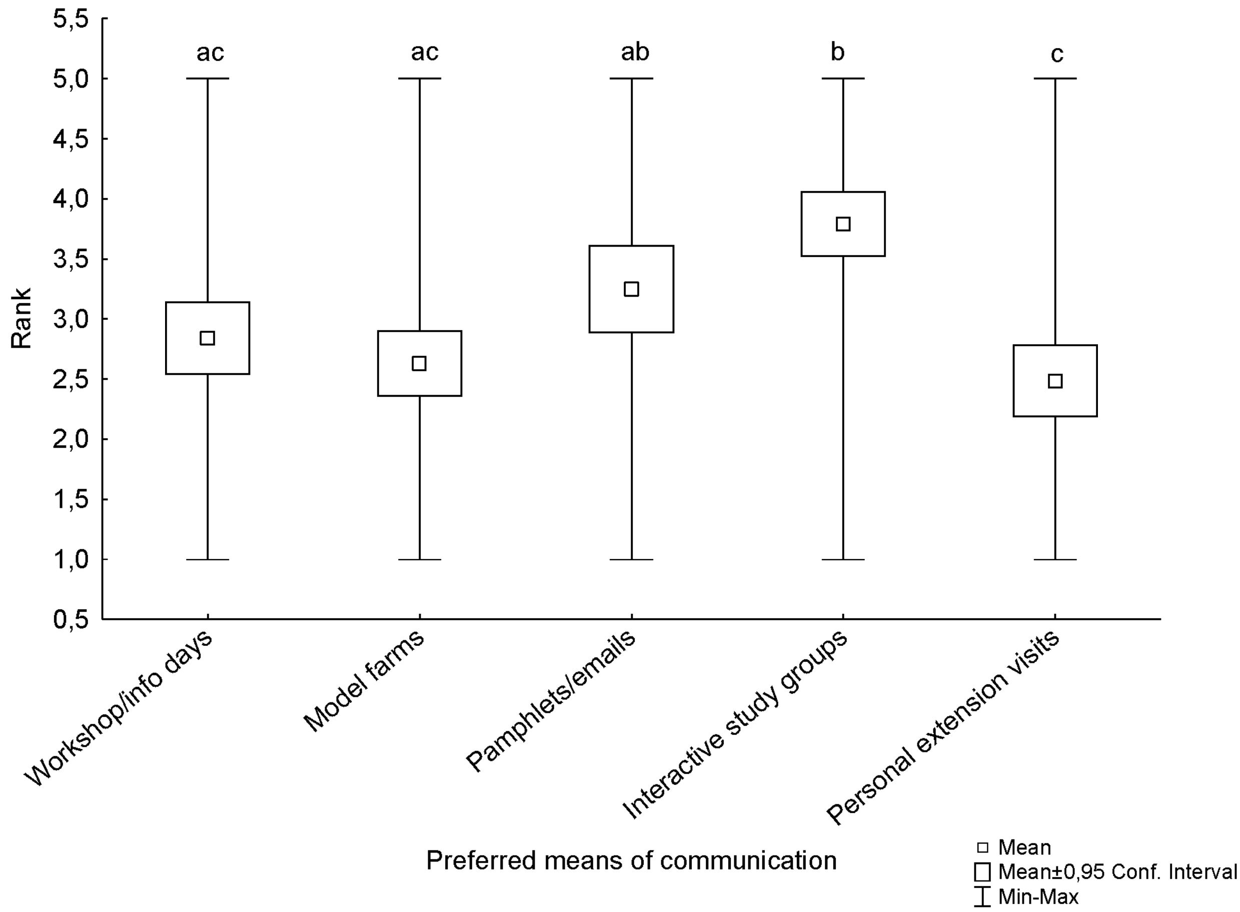


Figure 3.7. Box and whisker plots showing mean rank scores of extension methods favoured by LSGs. Letters indicate significant differences at $p < 0.05$ (low rank score denotes the most preferred extension method, while a high rank score denotes the least preferred extension method).

Farmers were asked open-ended questions about ways to improve the implementation of push-pull on coastal sugarcane farms, and what they considered were barriers to the adoption of push-pull in this region. The most frequently mentioned suggestion by farmers (27 % of all responses) was that field days, model farms, and demonstration plots would be the best way to improve the adoption of push-pull. Providing farmers with a cost-benefit analyses of push-pull and proof of the efficacy of push-pull were also mentioned by 16 % and 10 % of farmers respectively (Fig. 3.8). This demonstrates that farmers prefer first-hand experience of push-pull. They want to see push-pull working on other farms and they want to know for sure that push-pull will improve their yields before they employ it. Improved education, communication and collaboration with stakeholders, incentives, and extension outreach were also mentioned by LSGs as useful ways to successfully implement push-pull (Fig. 3.8). Although only 5 % of these discussions were concerned with providing better access to push-pull plants (Fig. 3.8), this may actually be an effective means of improving the uptake of push-pull in the coastal regions. A previously mentioned, many LSGs in this area do not know where to acquire push-pull plants, providing them with the plants may result in an increase in the adoption of this technology.

Most respondents (23 %) agreed that financial constraints were a barrier to the adoption of push-pull (Fig. 3.9). This further highlights the need for the development of a cost-benefit ratio for the implementation of push-pull on coastal farms. LSGs also mentioned that farmer attitudes towards new pest management techniques could be a barrier (16 %) (Figure 3.9). Some comments regarding farmer mind-sets include the following:

"Farmers don't want to change. It's easier for most to do what they have always done, to do what has worked in the past, even if it is not perfect."

"Practices like push-pull are not taken seriously. You advertise it as an environmentally-friendly way of controlling eldana, but farmers don't care. They want to see what's in it for them. It's a rands and cents game. If you can't show people that it will improve yield, then you won't convince anyone."

Most farmers think spraying is the only option, it is difficult to sway people to think otherwise.

Hard-headedness is your biggest problem. Like I said, try with the younger guys because older farmers are too stubborn to change the way they do things."

I think farmer receptivity might be the biggest barrier. Farmers don't like to study, and they want to see immediate results. This method is long-term, requires maintenance and is more difficult to understand (in comparison to insecticides), *so there will always be resistance to it.*

Another barrier mentioned by LSGs was the fact that push-pull is knowledge intensive (Fig. 3.9) The lack of institutional support, the lack of incentives and the perception that a large amount of maintenance needed to ensure the success of push-pull were considered as major draw backs (Fig. 3.9). Farmers were also worried about the practicality of push-pull (Fig 3.9). Topography and poor access to riverine/wetland areas were cited as being a hindrance from a practicality standpoint. This implies that push-pull should be implemented on a site-specific basis. When speaking about practicality, four farmers mentioned that they were worried about the wetlands becoming a source of infestation rather than a sink for *E. saccharina.*

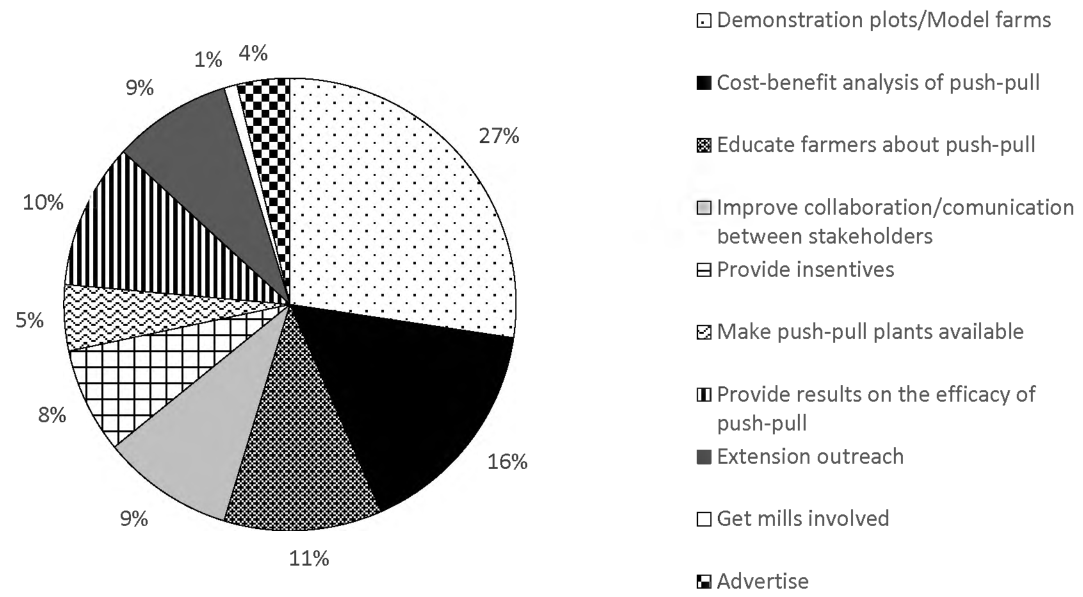


Figure 3.8. LSGs suggestions for the successful implementation of push-pull in the North Coast and South Coast sugarcane growing regions (number of mentions = 109)

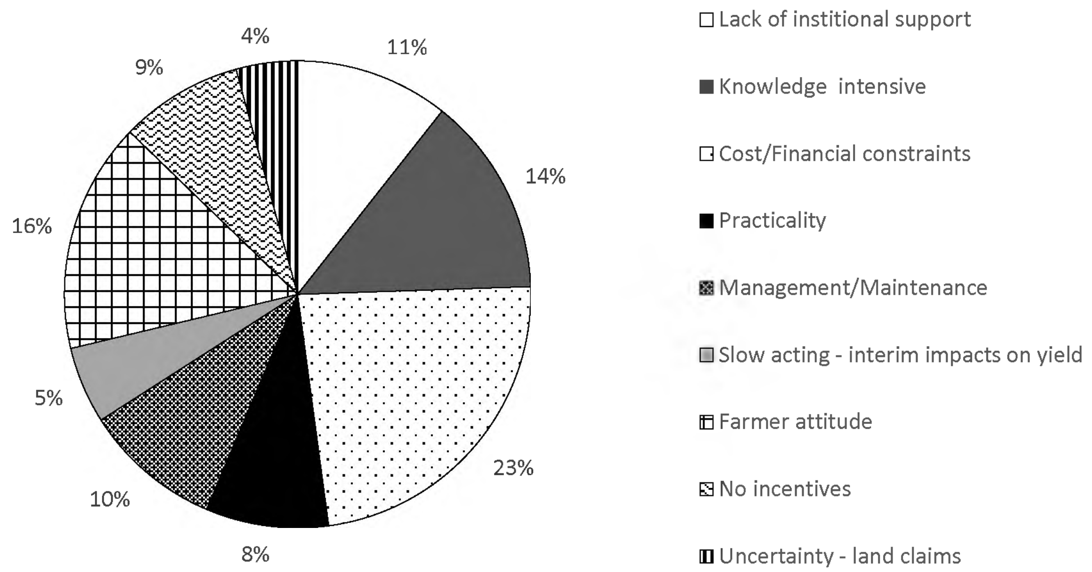


Figure 3.9. LSGs perceptions of barriers to the successful implementation of push-pull in the North and South Coast sugarcane growing regions (number of mentions = 94).

3.4. Discussion

Compared to farmers in the Midlands North, sugarcane farmers in the coastal sugarcane growing regions of KZN experience much higher levels of *E. saccharina*. Almost all of the LSGs interviewed on the North and South coast of KZN have had infestations of *E. saccharina* on their farms. This demonstrates the severity of the *E. saccharina* in this region, and hints at the damaging effect that this pest has on sugarcane production in the area. A number of farmers indicated that they had their *E. saccharina* problems "under control", however, most agree that this pest is a threat to the coastal sugarcane industry. In reality, LSGs in this area are losing huge sums of money each year because they are forced to harvest immature sugarcane as a direct result of the damage that can be caused by this pest (Lichakane & Zhou 2015).

The high levels of *E. saccharina* in the coastal regions of KZN means that there is a market for integrated pest management and new pest management tools such as PPT. Despite having heard of push-pull, coastal LSGs have a poor understanding of how push-pull works and the components that make up the push-pull program that is being implemented against *E. saccharina* in South Africa. Research has shown that a lack of knowledge with regards to implementation of IPM practices may lead to farmer uncertainty, which in turn results in a reluctance to adopt alternative management strategies (Shea et al. 2002). Furthermore, when pest pressures are high, farmers are likely to resist experimentation and stick to what they know (Shea et al. 2002). In the case of push-pull, it seems that farmers are more willing to cut their losses and harvest an early crop, than spend their valuable resources on a strategy, which they have no first-hand knowledge of, and which may ultimately result in the same outcome. This coupled by the financial constraints experienced by dry-land coastal farmers is potentially the reason for the slow adoption of PPT, despite its success as a preventative pest management tactic in the Midlands North. This was evident in discussions regarding the barriers towards IPM adoption, with many farmers complaining that they did not have the financial capacity to invest in new pest management strategies.

Reluctance to change is frequently mentioned by industry officials and the researchers who develop agricultural initiatives, but this can often be seen as a way of blaming farmers for non-adoption, rather than as an explanation their otherwise risk-averse behaviours (Rodriguez et al. 2008). It is important to note that several factors contribute towards the financial difficulties of coastal farmers, which may lead to their perceived "stubbornness". Under the RV payment system farmers are penalised for non-sucrose sugars that are an inevitable consequence of early harvest sugarcane (CANEGROWERS 2016). The shortening of the growing-season and multi-year drought conditions, in addition to *E. saccharina* infestations, has reduced the profitability of farms (CANEGROWERS 2016). Farmers in this survey recognise these constraints and have highlighted rainfall, pests, and decreases in soil quality as yield limiting factors in the coastal region (Fig. 3.1). LSGs are also faced with uncertainty with regards to long-term investments due to land claims and other land tenure issues, which was mentioned by respondents as a further potential barrier to push-pull adoption (Fig. 3.9) (BFAP 2014). The combination of these factors makes it difficult for coastal framers to effectively implement push-pull, and other sustainable management strategies such IPM and SUSfarms (Hurley 2013, BFAP 2014).

Agricultural support programmes can fail to encourage adoption due to inappropriate designs and a lack of meaningful incentives (Rodriguez et al. 2008). This is why direct communication with farmers is necessary to both diagnose and solve the problems of non-adoption (Rodriguez et al. 2008). In analysing the applicability of SUSfarms, Hurley (2013) mentioned that while the research at SASRI was well-conducted, farmer-researcher relationships were not ideal, and farmers had doubts over the applicability of said research. Farmers wanted to see the on-farm production and economic impacts of SUSfarms before accepting it (Hurley 2013). Similarly, coastal farmers highlighted the need for proper cost benefit analyses of pest management tactics, and the need for assistance and incentives to improve their crop production systems (Fig. 3.8). It is important to listen to farmer requests and suggestions when developing new management programmes, since farmers are the decision makers, and can veto any technology that they feel does not suite their farming requirements (Rolling et al. 2004). Therefore, as mentioned in Cockburn (2013), the perceived benefits of push-pull and have a meaningful impact on a farmer decision to implement the tactic (Kabii and Horwitz 2006). To gain a better understanding of the impacts of push-pull, a number of LSGs asked for more proof/results on the efficacy of PPT (Fig. 3.8). A study relating to this can be found in chapter 2 of this work. Farmer also indicated that they were reluctant to plant *Bt-maize* as part of push-pull. This is also addressed in chapter 2.

While *E. saccharina* and other stem borers cause approximately 47% (R930 million) of the pest related crop loss in the sugarcane industry, only 10% of SASRI's budget is spent on stem borer focused research (SASRI Committee meeting notes 2013). Unfortunately, this shows that the industry needs to invest more money and time into pest management practices and their dissemination. Education and extension are areas where improvements could be made. Although the majority of farmers learnt about IPM and push-pull through emails and pamphlets, a large number of LSGs indicated that they would prefer to have more frequent contact with extension offices and LPD&VCC especially when it comes to learning about pest management activities (Fig. 3.7). Farmers would also prefer more hands-on, experiential learning opportunities in the form of field-days and model farms. Farmers in Cockburn (2013) likewise expressed a desire for experiential learning opportunities and demonstrations of push-pull in the field improved the adoption of the technology in the Midlands North (Conlong et al. 2016). Khan et al. (2008a) also showed that interaction with extension officials positively influenced the likelihood of adoption of PPT. There is reason to believe that the same will hold true for LSGs in the coastal sugarcane growing regions of KZN. Particularly because many of these farmers expressed an eagerness to learn more about push-pull and reported that they were willing to be involved in further push-pull research (Table 3.2).

3.5 Conclusions

It is encouraging to note that there has been some uptake of push-pull practices amongst coastal farmers, with 8 respondents having reported that they employed some level of push-pull on their farms. Although they do not have all the components of push-pull in place, the majority of these farmers had begun rehabilitating wetland areas on their property, and some had already planted *C. papyrus* and *C. dives* as part of a push-pull initiative. This indicates that with further research, and development of push-pull, adoption of this technology and other IPM practices will increase with time.

Chapter 4

Assessing the feasibility of push-pull for the control of *Eldana saccharina* for use by small-scale sugarcane growers in the South Coast and Lower South Coast sugarcane growing regions of Kwa-Zulu Natal

4.1. Introduction

Smallholders, or small-scale famers, are described as rural cultivators, who practice intensive, permanent and diversified agriculture on relatively small plots of land in areas of dense population (Netting 1993). In South Africa, where a history of racial dispossession has resulted in a 'white' dominated commercial agricultural sector, smallholder agriculture is seen a means of addressing inequities through the promotion of rural development, job creation, poverty reduction and land reform in some of the poorest areas of the country (O'Laughlin 2013, Pienaar and Taub 2015). In addition to this, subsistence agriculture and small-scale farms in South Africa contribute towards household and regional food security (Baiphethi and Jacobs 2009). As such, it is important that South African small-scale farmers are supported through the provision of subsidies and improved technologies (Pienaar and Taub 2015). Research has shown that when small-scale farmers have access to appropriate safety nets, enterprise skills, new innovations and market access they can be empowered to boost production, improve nutrition and increase their incomes (Agriculture for Impact 2013). This improves not only the farmers own situation, but also results in them contributing towards the local and national economy (Agriculture for Impact 2013).

The sugarcane industry in South Africa is unique, in that the majority of small-scale sugarcane growers (SSGs) are commercial farmers (Eweg 2005). Smallholders make up the majority of the total number of sugarcane growers registered in the country (SASA 2014). As such, SSGs form an integral part of the industry. Their contribution towards the sustainability and long-term growth of South African sugarcane production is invaluable (Eweg 2005). However, like most South African agricultural sectors, the sugarcane industry is dualistic in nature (Eweg 2005, Pienaar and Taub 2015). On one hand, it is comprised of a well-integrated and highly capitalized commercial sector of 1383 large-scale farmers, who produce 83.3 % of the total sugarcane production (SASA 2014, Eweg 2005). On the other hand, there are approximately 21 110 resource poor, small-scale farmers, who only produce 9,4 % of the total crop (SASA 2014, Eweg 2005). This means that, while 94 % of registered sugarcane growing farmers are classified as SSGs, these growers are producing a comparatively low amount of sugarcane (SASA 2014). Low-productivity and high input costs (fertilizer, labour and transportation) mean that SSGs do not have the capital to reinvest in future sugarcane crops (Mahlangu and Lewis 2008). As a result, they are producing markedly lower yields of sugarcane per ha than their large-scale counterparts (Sibiya and Hurley 2011). Consequently, the number of SSGs in South Africa has declined dramatically in recent years, from 50 000 growers in the early 2000s (Eweg 2005), to the 21 110 growers registered in 2013/2014 (Eweg 2005). One means of directly improving crop production and therefore SSG sustainability, is through better management practices (BMPs) (Maher 2007, Cockburn 2013).

BMPs seek to minimise the negative impacts that sugarcane farming has on the environment, whilst also enhancing the sugarcane yields and subsequent financial returns of SSGs through improved farming practices and better management (Mahlangu and Lewis 2008). Poor plant nutrition, inadequate water supply and lack of access to inputs, predispose smallholder crops to attack by pests and diseases (van Huis and Meerman 1997). As such, integrated pest management (IPM) has been highlighted as a BMP that can help to improve smallholder yield deficits, whilst simultaneously minimizing the harmful effects of farming on the environment (van Huis and Meerman 1997). Moreover, smallholders generally engage in practices that are well suited to, and are often included in IPM frameworks (Khan et al. 2014). IPM practices, such as habitat management and push-pull technology (PPT), stand to be particularly beneficial to small-scale growers. These techniques rely on cultural pest control methods, such intercropping and crop rotation, that are already employed by small-scale farmers and are therefore familiar to them (Kahn et al. 2014).

Eldana saccharina is considered as the most economically damaging pest on sugarcane in South Africa (Keeping et al. 2006). Although *E. saccharina* infestations are generally found to be lower on small-scale sugarcane farms than on large-scale sugarcane farms, it is still advised that SSGs are made aware of the management strategies that can be employed against this pest (Way et al. 2003, Goebel et al. 2005, Cockburn 2013). As a means of controlling *E. saccharina*, PPT has been recommended by South African Sugarcane Research Institute (SASRI), as part of a wider IPM programme, to be used against the pest. PPT has the potential to increase the productivity of sugarcane in areas where the pest is damaging, as well as protecting those areas from further infestation (Barker 2008, Cockburn 2013). Unfortunately, despite the potential of such practices to improve the livelihoods of small-scale farmers, and despite efforts at setting up an effective extension support network in the South African sugar industry, SSGs seem unwilling, or unable to adopt BMPs (Owens and Eweg 2003, Eweg 2005, Mahlangu and Lewis 2008). The lack of adoption of BMPs has been primarily attributed to the financial and institutional constraints that SSGs face (Owens and Eweg 2003, Parsons 2003, Cockburn 2013).

Overall, the implementation of IPM in sub-Saharan Africa has been largely unsuccessful (van Huis and Meerman 1997, Orr 2003, Meijer et al. 2014). Especially amongst resource-poor farmers (van de Fliert and Braun 2002, Orr 2003). There are many complex reasons for the low levels of IPM adoption among small-scale farming communities in sub-Saharan Africa (Orr 2003, Meijer et al. 2014). However, the traditional top-down approaches that underpin many agricultural development programmes are said to be a key factor in the lack of adoption of sustainable agricultural technologies in this region. Such approaches typically follow linear models of dissemination, whereby new knowledge is developed and tested by scientists and then passed down to farmers via extension services (Stephenson 2003, Leeuwis 2004, Godin 2006, Knickel et al. 2009). The linear diffusion, or 'transfer-of-technology' (TOT), model for agricultural research has built-in biases which favour resource-rich farmers (Chambers and Ghildyal 1984). They are said to advocate agricultural technologies that are not relevant to small-scale farmers, or neglect to provide small-scale farmers with sufficient information for adoption (Chambers et al. 1989). Since all individuals and farms are different, it is important to recognise that new technologies are not always suited a small-scale growers' situation (Stephenson 2003, Röling et al. 2012). This highlights the need for participatory research when it comes to the development and implementation of IPM programmes for SSGs (Cockburn 2013). Growers should be able to communicate their needs, misgivings and ideas to extension officers and researchers so that technologies can be revised and tailored to suite the individual farmers' needs (Röling et al. 2012). Ultimately, farmers are responsible for their own management decisions and have the power to veto any new technology that is not suited to their specific on-farm requirements (Röling et al. 2004, Cockburn et al. 2003). By working closely with the growers and relevant stakeholders, researchers can better recognise and understand the needs and constraints of farmers and develop IPM practices that are more appropriate and therefore easier to implement (van de Fliert and Braun 2002).

The farmer first approach has been used to successfully implement an IPM programme to control rice pests and reduce the use of harmful pesticides on irrigated rice farms in Asia (Matteson 2000). Rice farmers were empowered to learn about and implement the IPM programme through farmer field schools (FFS) (Matteson 2000). FFS are educational tools that use experiential and group learning techniques as a means of extension. They assist farmers in improving their decision-making processes and problem-solving skills, and facilitate the learning of new techniques in a practical, hands-on manner. Farmer-to-farmer extension, in the form of FFS, farmer teachers and demonstration field days, also helped to improve the adoption of PPT amongst small-scale maize farmers in Kenya (ICIPE 2007, Amudavi et al. 2009, Khan et al. 2014). Farmers perceptions of pests and the factors influencing their adoption of PPT were analysed and used to improve the dissemination of the technology in the Kenya (Khan et al. 2008a).

Participatory research, farmer-friendly policies and education are seen as pathways towards the improved adoption of sustainable farming techniques and BMPs by sugarcane farmers in South Africa (Hurley 2013). Following the successful uptake of PPT in Kenya and other East African countries, Cockburn (2013) conducted an exploratory study to assess the feasibility of implementing PPT for the control of *E. saccharina*, on SSG farms in the Midlands North region of the South African sugarcane industry. Before this study, no attempts had been made to encourage the implementation of PPT by SSGs in the South African sugarcane industry (Cockburn 2013). The results revealed that *E. saccharina* was not perceived by SSGs to be a major constraint to small-scale sugarcane production in the Midlands North region of KZN. As such, PPT for the control of this insect is not considered as a priority for these farmers. SSGs in this area perceived weeds and high input costs as the major constraints to their sugarcane production. Therefore, Cockburn (2013) recommended that more extension resources be invested into weed management and that efforts be made to reduce SSGs input costs (Cockburn 2013). By working closely with the farmers, this research was able to pinpoint the immediate needs of the SSGs in the Midlands North. However, to get a better understanding of the diversity of constraints that affect the production of sugarcane amongst SSGs, further studies need to be conducted in other areas of the South African sugarcane growing region (Cockburn 2013).

Eldana saccharina numbers are typically higher in the coastal sugarcane growing belt of KZN (Assefa et al. 2008). It is likely that the pest poses more of a threat to SSGs in this area (Cockburn 2013). The aim of this chapter was thus to explore the feasibility of implementing push-pull for control of *E. saccharina* in sugarcane in the SSG community of the South Coast region. The objectives of the study were to assess the role that sugarcane plays in the livelihoods of SSGs and to determine the SSGs main sugarcane production constraints. The SSGs perceptions and knowledge of pests and pest management were assessed. This was done to determine whether PPT was a useful tool for pest management in this area, and whether the technology could be tailored to suite the pest management strategies of small-scale sugarcane farmers. Insight into SSGs farming systems is severely limited within the South African sugarcane industry (Eweg et al. 2009, Cockburn 2013). Therefore, the knowledge gathered from this study will also be used to add to the current understanding of small scale sugarcane farms.

4.2. Materials and Methods

Methodology for this research was similar to the research conducted in chapter 3 and of the work done by Cockburn (2013), so that the results were comparable. The results of this chapter will lead to the development of an improved knowledge base for the facilitation of push-pull amongst SSGs in other sugarcane production regions of South Africa. It will also lead to a better overall understanding of SSGs needs, constraints and pest management practices.

4.2.1. Study Site

This research was conducted in the South Coast and Lower South Coast sugarcane growing regions in KwaZulu-Natal, South Africa. SSGs in these regions supply sugarcane to the Illovo Sugar (South Africa) Limited mills at Sezela (30°40'75.89"S, 30°67'88.47"E) and Umzimkulu (30°43'57.7"S 30°26'34.6"E) in KwaZulu-Natal (Figure 4.1) (SASA, 2014). In the 2015/2016 season 1 834 SSGs delivered approximately 66 434 tons to the Sezela Mill. A further 160 SSGs delivered an estimated 22 290 tons of sugarcane to the mill at Umzimkulu. The total area under sugarcane, farmed by small-scale growers in these two regions, is 2453 hectares. From these data, it was extrapolated that the average yields for SSGs during this season were 36.2 tons of sugarcane per hectare or 44.5 tons of sugarcane per grower (Patrick Ncgobo, pers. comm., 2015).

Multiple stakeholders are involved in the development of SSGs in the South Coast and Lower South Coast regions. These stakeholders are engaged in funding, training and supporting the local small-scale sugarcane farmers. Major role players include the South African Sugarcane Research Institute (SASRI), the Department of Agriculture and Rural Development (DARD), the South African Cane-growers Association (CANEGROWERS), the Illovo Millers and Miller Group Boards and the South Coast and Lower South Coast local pest, disease and variety control committees (LPD&VCC). Table 4.1. outlines the role of each of these stakeholders within the SSG community.

In Cockburn (2013), researchers purposefully chose to work with SSGs that delivered sugarcane to the Noodsberg Mill, specifically those who were involved in local grower groups and extension activities. The same criteria were used to decide which SSGs would be included in this study. Poverty, vulnerability and a lack of institutional support amongst small-holder farming communities has been shown to negatively impact the implementation of new agricultural technologies, such as PPT (Fafchamps 2009, Shiferaw et al. 2009). Marginalized farmers are often reluctant to adopt new agricultural innovations because of they are afraid to invest their already limited resources into practices that are untried, unfamiliar and not guaranteed to produce returns (Meijer et al. 2014).

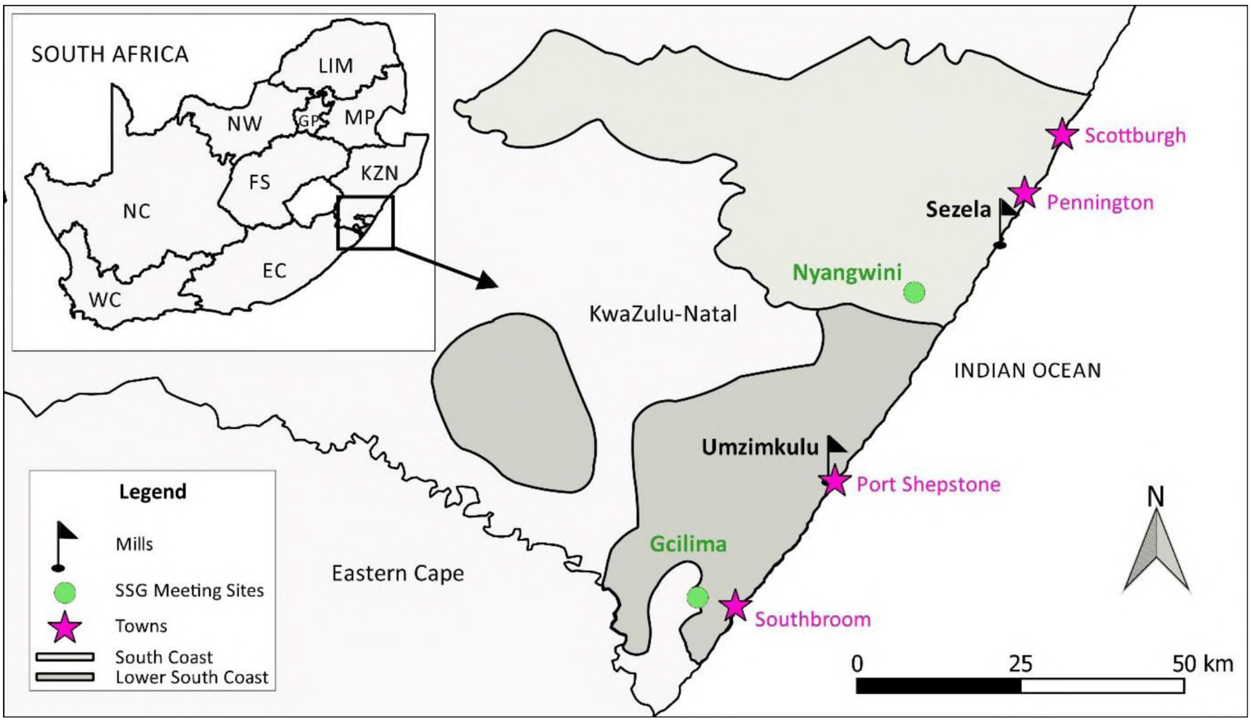


Figure 4.1. Map South Coast and Lower South Coast sugarcane growing regions of KZN, SSG meeting sites indicated in green: Nyangwini on the South Coast; and Gcilima on the Lower South Coast.

It is probable that commercially active small-holders are the least economically vulnerable members of the farming community and are therefore more likely to be able to accept and implement new pest management strategies (Cockburn 2013). This is why we chose to work with SSGs who delivered their sugarcane to the mill. However, it is important to note that poor, marginalized, elderly and female farmers are often neglected in agricultural studies because of institutional bias (Aliber 2003, Francis 2006, Chambers 2008). These members of the community play a vital role in the development of small-holder agriculture in South Africa and it is important that they are not forgotten (Francis 2006). It is our hope that this research will contribute to a better understanding of the livelihoods and agricultural practices of SSGs, so that the wants and needs of these farmers can be addressed in future agricultural research and development endeavours. A concerted effort was made to include woman farmers in the study because of the widely recognised and important role that they play within the rural agricultural sphere in South Africa (Altman et al. 2009, Eweg et al. 2009).

The South Coast sugarcane growing region was identified as an advantageous area to continue and improve upon the work done by Cockburn (2013) on the implementation of push-pull for the management of *E. saccharina* in the Midlands North. *Eldana saccharina* is recognised as a major constraint to the production of sugarcane in the South Coast region (Goebel et al. 2005). As such, it was chosen as an appropriate location to test the suitability of push-pull to control *E. saccharina* in sugarcane and to test its potential to act as a preventative measure to stop the spread of the pest into other less infested areas. SSGs in the South Coast hadn't yet been exposed to PPT and as such, the study conducted here aimed at assessing whether push-pull was an appropriate pest control strategy for small-scale farmers in this region. The study range was later expanded to include SSGs from the Lower South Coast region. This was done to ensure that a SASRI extension officer or DARD agricultural advisor was always available to attend meetings and grower visits alongside the main researcher. The presence of at least one of these officials at every meeting/visit helped to ensure grower confidence and participation. However, the extension officers and agricultural advisors in the South Coast region were not always available during the sampling period. By expanding the sample range, we ensured that the study was not hindered by time constraints and that a larger number of SSGs were able to participate in the surveys.

Table 4.1. Stakeholders involved in the development of small-scale growers in the South Coast and Lower South Coast sugarcane growing region.

Stakeholder	**Role**
South African Sugarcane Research Institute (SASRI)	An agricultural research institute that also provides extension services and educational courses for growers.
Department of Agriculture and Rural Development (DARD)	Supporting farmers through agricultural development programmes. Aims to promote economic growth, food security and advancement of rural communities in KwaZulu-Natal by providing farmers with funding, education, improved infrastructure and technology transfer services.
South African Canegrowers Association (CANEGROWERS)	Organization representing farmers in the sugarcane industry. Offers training and development opportunities to farmers who want to improve their technical, financial and leadership skills.
Illovo Sugar (South Africa) Limited	Sugar producer in the region. Responsible for the production operations at Sezela Mill and Umzimkulu Mill. Assists with the development of SSGs by accessing government funding for development. Works with SSGs and other stakeholders to insure sustainable sugarcane supply.
Mil Group Board (MGB)	Committee representing SSGs (drawn from local grower groups) at the mill and liaising with contractors for harvesting and haulage activities.
Local Pest Disease and Variety Control Committees (LPD&VCC)	Provides pest and disease monitoring services to farmers and provides extension support related to pest & disease management.

4.2.2. A mixed methods approach to data collection

Exploratory studies typically require two phases of data collection, quantitative data collection followed sequentially by qualitative data collection (Creswell 2009). Nyanga (2012) stated that, "While quantitative methods are useful for showing scale, trends, patterns, tendencies and generating generalizations, they are limited in explaining the context under which various factors influence the adoption of an innovation". When used in conjunction with quantitative data, qualitative methods are able to provide additional information on social dimensions and various other processes that effect how and why small-scale farmers make decisions regarding the adoption of agricultural technologies (Nyanga 2012). A mixed methods approach can lead to a better understanding of the needs and wants of a community, than a single research strategy approach (Creswell 2009). As such, a mixed methods approach was used for data collection in this study. In keeping with work done by Cockburn (2013), a combination of quantitative, qualitative and participatory approaches to sampling was employed (Sinzogan et al. 2004, Mayoux and Chambers 2005, Creswell 2009). All data collection activities were conducted in isiZulu (with the help of a translator), which is the home language of the SSGs in the study area.

4.2.3. Sampling

Research activities were divided into 3 phases. The first phase was conducted via individual surveys and house visits, while the second phase centred around focus group discussions (FGDs). These phases were concentrated specifically on data collection and were used to gain an understanding of SSGs, their farming techniques and their major constraints and expenses. The third phase of the study focused on SSG workshops. During the workshops, push-pull was explained, demonstrated and discussed for the benefit of the farmers. They were given an opportunity to express their thoughts on push-pull technology and give feedback as to whether or not they approved of it as a pest management technique. The outlines for each of the research phases, and the number of participants involved in each phase can be found in Table 4.2.

Table 4.2. Research activities and the sample number of small-scale grower participants for each phase of the research.

Research phase	**Activities**	**Sample numbers**
Phase 1	**Individual surveys:** Unstructured interview, participatory sketch mapping, matchstick scoring matrix and agronomic knowledge survey	35 individuals (house visits and prearranged meetings)
Phase 2	**Group Meetings:** Focus group discussions (FGDs), insect identification and free-listing activities about insects and pest management	58 individuals (5 meetings)
Phase 3	**Workshops:** Presentations about integrated pest management, push-pull and beneficial insects. Workshops included group discussions about the implementation of push-pull on SSGs farms	37 individuals (2 meetings)

4.2.4 Introduction to SSGs and commencement of research

The main researcher in this study was introduced to the SSGs and stakeholders through attendance at farmer's meetings, workshops and field days. These meetings were typically hosted by SASRI, DARD or the South African Canegrowers Association. The research project was introduced and explained by the SASRI extension officer at these meetings. Participants for the individual surveys were identified from members of the community who were present at the introductory meetings. Only SSGs who expressed an interest in contributing to the research were chosen to participate in the individual surveys. After initial introductions were made, the main researcher was able to organise dates and times for individual surveys and additional meetings which were held specifically for focus group discussions. The researcher was accompanied by one of the SASRI extension officers or by a DARD representative at all individual surveys, house visits and focus group discussions. Once the individual surveys and focus group discussions were completed, participants were invited to attend push-pull workshops.

It was important that the small-scale farmers felt reassured and confident during the study and that a high level of trust was developed and maintained between all the participants and researchers involved. We felt we gained a good understanding of SSGs through our involvement at meetings and field days and through subsequent interactions with the community. A number of SSGs commented on the frequency of our visits to the community and expressed appreciation at the level of respect that we showed them. The main researcher was also presented with gifts of seed as a gesture of good will. We thus felt accepted within the communities that we worked with and were confident that the participants were familiar with us and were able to engage with us freely.

4.2.5. Data collection

4.2.5.1. Data collection phase 1: Individual surveys

The first phase of the study involved individual interviews with SSGs. A total of 35 SSGs were selected for individual interviews. They were interviewed during house visits or else they were interviewed at local community meeting halls. In addition to unstructured, open ended questions, three other activities were used during the individual interviews. Participatory sketch mapping, free listing and participatory matrix scoring were employed to help the researchers learn more about each participant's farm and farming activities. Guidelines on how to run the participatory sketch map and scoring matrix activities were taken from Cockburn (2013), but such research strategies are also explained and discussed in Pretty et al. (1995) and Chambers (2002).

Prior to the commencement of each survey, the SSG being interviewed was asked if they were willing to participate in the research. The purpose of the interview was explained to the participant and their anonymity was guaranteed. The participants were then asked by the researcher to draw a sketch map of their farms and farming activities (Figure 4.2 A). The tools needed to draw these maps were provided by the researcher. The maps were used to facilitate discussion about the SSGs different agricultural enterprises and the benefits, constraints, and activities associated with these enterprises. This activity was able to place the SSG in the unique position of being able to teach the researcher directly about their farm. Once the sketch map had been completed, SSGs were asked a series of closed and open-ended questions. The questions were aimed at helping the researcher to understand how farming contributes to the interviewees' livelihood. Questions about the farmer's socio-economic status were also asked. These included questions regarding age, gender, size of household, number of working household members and main sources of income. Free-listing activities were used in addition to the questions to identify the farmer's most important crops and to identify their major agricultural constraints.

During the individual interviews, SSGs were also asked questions about sugarcane pests and pest management techniques. These questions were aimed specifically at testing the SSGs crop protection knowledge and practices (Midega et al. 2012, Cockburn 2013). Farmers' knowledge of sugarcane pests was measured by evaluating whether farmers were able to identify pests by name (local, isiZulu, common and taxonomic names were all considered suitable), describe their features and discuss the type of damage they caused to the crop. Farmers' knowledge of sugarcane pest control practices was measured by evaluating whether farmers were able to identify a management technique, describe the technique and discuss which pests the technique was used for. The farmer's knowledge of sugarcane pests and pest control practices was scored using a ranking method as described by Midega et al. (2012). The scores ranged from 0 to 3 (Midega et al. 2012). 0 = No knowledge, 1 = Low knowledge, 2 = Medium knowledge and 3 = High knowledge (Midega et al. 2012). The scores were recoded along with notes of each farmer's response to the questions asked. This was done for validation purposes and to avoid subjectivity. The questions asked of SSGs to assess their knowledge of sugarcane pests and pest control practices were; a) Do you know what are the main pests of sugarcane in the area, and b) Have you seen pests in your sugarcane, and how do you control the sugarcane pests?

Finally, the SSGs were asked to fill in a participatory matrix scoring system. The researcher drew the matrix for each participant. The top row of the matrix indicated the inputs and outputs of the various agricultural enterprises that are employed by SSGs (inputs include costs, labour and time; outputs include income and food). The SSGs were then asked to identify their top five agricultural enterprises.

These enterprises were listed in the first column of the matrix, so that the matrix resembled a table (Figure 4.2 B). The interviewees were given a box of 220 matches. They were asked to divide all the matches between the different cells and thereby indicate how much each enterprise cost (inputs) or earned (outputs) them. A large number of matches denoted a higher cost or income. A smaller number of matches signified fewer expenses or less returns. By limiting the number of matches allocated to each individual (220 matches each), we were able replicate the matrix more successfully. Restricted overall scoring allows for more rigorous testing and a better analysis of the results (Maxwell and Bart 1995, Cockburn 2013). Such methods also helped us to gain a better insight into the true worth of different agricultural enterprises (Maxwell and Bart 1995).

Figure 4.2 A: A sketch map drawn by an SSG from Umzumbe showing his household and agricultural activities. **B**: Small-scale growers from Gcilima using the matchstick scoring matrix to illustrate inputs and outputs of their top five agricultural activities.

The individual surveys were used to answer the following research questions:

- What livelihood strategies are employed by SSGs?
- How does farming contribute to SSGs livelihoods?
- What role does sugarcane play in SSGs livelihoods?
- Which other agricultural enterprises are important to the livelihoods of SSGs?
- What are SSGS major sugarcane production constraints?
- How much do SSGs know about sugarcane pests and pest control techniques?

4.2.5.2. Data collection phase 2: Focus group discussions

The second research phase involved group meetings, which included focus group discussions (FGDs) and free-listing activities with groups of SSGs that ranged in size from six to twenty SSGs. FGDs can be described as interactive discussions that focus on a specific topic or set of issues (Hennink 2013). The discussions take place between a preselected group of people who have a shared experience of the issues at hand (Hennink 2013). The participants are led by a moderator, who facilitates conversation about the chosen topics, without specifically directing the discussion (Nyariki 2009, Krueger and Casey 2015). This allows participants to express their views freely and spontaneously, so that the moderator can gain a better understanding of the research topic from the perspectives of the participants themselves (Nyariki 2009, Krueger and Casey 2015). FGDs and other participatory research techniques are recommended as effective tools for understanding farmer's priorities and constraints, as well as for gathering data on farmer's knowledge and perceptions of pests, pest management practices and agricultural technology (Johnson et al. 2003, Williamson et al. 2008, Nyariki 2009, Litsinger et al. 2009).

Colucci (2007) highlights the advantages of including exercises within the focus group agenda that act as enjoyable and productive supplements to verbal questions. Activity oriented questions are often better able to engage participants, promote discussion and focus the attention of the group on the core topic of the study (Krueger 1998, Bloor et al. 2001). In addition to this, group exercises are inclusive, and help to involve participants who are less comfortable with making verbal contributions (Colucci 2007, Nyariki 2009). With this in mind, some exercises were included during the FGDs as a different means eliciting answers and facilitating discussion amongst SSGs. Free-listing activities and specimen, identification activities were used as exercises during the FGDs, as these were well suited to the meeting agenda. Free-listing is an ethno-biological methodology that is used in anthropology to quantify people's knowledge within a certain domain (Quinlan, 2005, Cockburn 2013). The free-listing activities were used in conjunction with insect specimens to facilitate discussions about the role of pests and other invertebrates within the agro-ecosystem.

Overall, 58 SSGs were involved in this phase of the research and a total of five FGD meetings were held at various locations within the study area. The larger FGDs were divided, by gender, into sub-groups. Cockburn (2013) found that this ensured better participation by woman, whose contributions are sometimes lost in larger, male dominated, group discussions. The FGDs were facilitated by the local SASRI extension officer, DARD agricultural advisors and student researchers. The guidelines for the FGDs and related activities were taken from Cockburn (2013).

The following research questions and activity outlines were taken directly from chapter 3 of the work done by Cockburn (2013).

The FGDs were used to answer the following research questions:

- Which sugarcane pests do the SSGs know?
- Which food crop pests do they know? (to use for comparison to sugarcane pests)
- Which do they consider to be the worst sugarcane pest/s?
- Do they know about beneficial insects (i.e. do they have any understanding of insect biological control?)
- What do they do to control insect pests: in sugarcane and food crops (for comparison)?

To comprehensively address the research questions above, FGDs were divided into three activities:

1. Free-listing of insects observed on their farms; The respondents were divided into groups and instructed to compile written lists of insects according to the following categories:
    - Insects which they have seen in sugarcane
    - Insects which they know are pests of sugarcane
    - Insect pests which they have seen in their food crops.
2. Identification and naming of insects in the insect box (dried pinned insect specimens) and on photographs. This activity helped to facilitate discussion about insects and insect pests. Both specimens and photographs were used to ensure that SSGs could identify the insects (Mkize et al. 2003).
3. Discussions about free-listed insects, specimens in the insect box and photographs, and time allocated for additional questions for clarification purposes.

4.2.5.3. Data collection phase 3: Push-pull workshops

After the individual surveys and FGDs had been completed, the SSGs were invited to attend a push-pull workshop in their area. Two workshops were held. One workshop was held in the Lower South Coast region at the community meeting hall at Gcilima (30°55'14.1"S 30°15'14.7"E) and one was held in the South Coast region at the training centre at Nyangwini (30°30'07.2"S 30°33'06.3"E). A power point presentation was prepared for these meetings to help explain the advantages of IPM, PPT and beneficial insects to the growers (Fig. 4.3). Samples of the push-pull plants *Melinis minutiflora*, *Cyperus dives* and *Cyperus papyrus*, were also bought to the workshops for demonstration purposes and so that the growers could inspect plants. After the presentation had been completed the growers were able to ask the main researcher questions about PPT and its implementation. An informal discussion was initiated by the main researcher and the representatives of SASRI and DARD. Growers were encouraged to express their views of IPM and PPT and to voice any concerns that they had with the technology. The growers were also asked if they would consider attending more PPT workshops and whether or not they thought this technology would be useful on their farms. The question and discussion period was recorded and the SSGs response towards PPT was included in the qualitative analysis of this study.

Figure 4.3. A push-pull workshop being held for the benefit of SSGs at the Gcilima community hall in the Lower South Coast sugarcane growing region of KZN.

4.2.6. Data analysis

All quantitative data was analysed using Microsoft Excel and Statistica version 12.

4.2.6.1. Individual surveys

Descriptive statistics were used to report the SSGs' responses from the individual interviews. Percentages, frequency distributions and salience indices (refer to 4.2.6.2 for more information about salience indices) were used to analyse answers to the open-ended questions that were asked during the survey. These data were displayed using graphs and pie charts. Qualitative content analysis was used a method for examining the participants' responses and for the accumulation of data material according to recurring themes and categories (Kohlbacher 2006). Through the content analysis, pertinent discussion points, phrases, responses and answers to certain questions were identified and reported in the results section.

Sketch maps were collected and used mainly as a qualitative data source (Cockburn 2013). The maps were analysed by comparing the relative size of sugarcane fields to those of other agricultural enterprises (Cockburn 2013). This served as a complement to other data sources. Sketch maps also served to reinforce the SSGs responses regarding important agricultural enterprises and livelihood strategies.

The main agricultural enterprises identified by the individuals were analysed using free-lists. Once again, this data was analysed using a salience index and frequency graphs. The top five agricultural enterprises were also used to construct the matchstick matrix scoring system. In the matchstick matrix scoring system, the total number of matches placed in each cell of the matrix were counted per respondent. This data was tabulated as a quantitative measure of the role that various agricultural enterprises play in the lives of individual SSGs. The mean number of matches allocated towards inputs and outputs of sugarcane and non-sugarcane agricultural enterprise was calculated across all participants. The mean scores (i.e. number of matches) for each variable were displayed using a box and whisker diagram. Confidence intervals and standard deviations around the mean were used to determine variability within the data. A comparison of mean matrix scores allowed us to assess the relative importance of different agricultural enterprises within the SSG community. ANOVA was used to test for significant differences ($p < 0.05$) between the inputs and outputs of sugarcane and non-sugarcane enterprises.

SSGs knowledge scores of sugarcane pests and pest control techniques were recorded. The mean scores in each category were calculated to determine the overall knowledge of SSGs. The number of individuals that recorded each particular score were also recorded. This information was used to generate a stacked column chart to show the distribution of sugarcane knowledge within the small-holder community. Once again, the participants' responses to the questions regarding sugarcane pest and pest control knowledge were analysed qualitatively as a supplement to the quantitative data that is reported in the results.

4.2.6.2. Focus group discussions

Data gathered from focus group discussions and the related activities were quantitatively analysed using tables, pie charts and frequency distributions. The answers to the questions posed in 4.2.5.1 above were categorised into topics. Recurrent themes and answers allowed these topics to be further divided into pertinent categories. The frequency of mention of each category within a topic was recorded and these results were displayed pie charts. The pie charts were displayed alongside qualitative data, which acts as a descriptive code, or narrative text (Table 4.4).

The free listing activities were analysed according to frequency of mention and displayed in graphs. The percentage of mentions within each topic was further analysed using a salience index (Si). Saliency indices are used to determine the cognitive salience of a specific item within lists that have been generated by a group of respondents. In other words, the salience index of an item is able to describe the fundamental importance of a specific domain amongst a group of people. This is done by analysing the frequency of mention of items across a number of lists, as well as the order of items within those lists (Smith 1993). The Salience index used here is described in Smith and Borgatti (1997). It is an adaptation of the ones proposed in Smith (1993) and Borgatti (1996). For each item mentioned in the free lists, the salience index is calculated as:

$$S = ((\Sigma\ (L - R_j + 1))/L)/N$$

In this formula, S is the average rank of an item across all lists in the sample (Smith and Borgatti 1997). S is weighted by the lengths of the lists in which the item was mentioned (Smith and Borgatti 1997). L is the length of (number of items in) each individual list, R is the rank of item j in the list (the first item in a list = 1) and N is the number of lists in the sample (Smith and Borgatti 1997). This version of the salience index ensures that items mentioned last in a list have a higher cognitive salience than unmentioned items (Smith and Borgatti 1997). As such it is a more accurate measure of saliency (Smith and Borgatti 1997).

4.2.6.3. Push-pull workshops

The questions, suggestions and opinions of SSGs regarding push-pull and its implementation were recorded and reported qualitatively in the results section.

4.3. Results

Of the 35 individuals interviewed, 62.8 % were male and 37.2 % were female. The average age of respondents was 51.9 (± 11.7) years old and 25.7 % of respondents were over the age of 60. The typical household was made up of 6.8 (± 2.6) people, of which 2.1 (± 0.8) people worked or bought in an income. The mean area of sugarcane grown by the SSGs interviewed was 2.6 ha.

4.3.1. The role that farming plays in SSGs livelihoods

4.3.1.1 Results from interviews

The results from the individual surveys show that farming, in particular sugarcane farming, plays an important role in the livelihoods of SGGs from the southern coastal regions of KZN. SSGs also rely heavily on their families and local communities. When asked about which factors allow the farmers to reside in the area, many individuals referred to their families and other social structures as influencing their decision to live and stay in the southern coastal regions (Fig. 4.4). The sample group also highlighted their farms as a determining factor when it comes to their decision to live within the study area (Fig. 4.4). Furthermore, a large portion of SSGs (37 %) listed sugarcane farming as their main source of income (Fig. 4.5). A further 9 % of the small-holders stated that other farming enterprises form the bulk of their income (Fig. 4.5). This means that, farming in general is vital to the financial security of SSGs in within the communities sampled. Grants, especially state pensions, are also an important source of income for SSGs, whilst fewer SSGs relied on formal employment and business as a major form of revenue (Fig. 4.5).

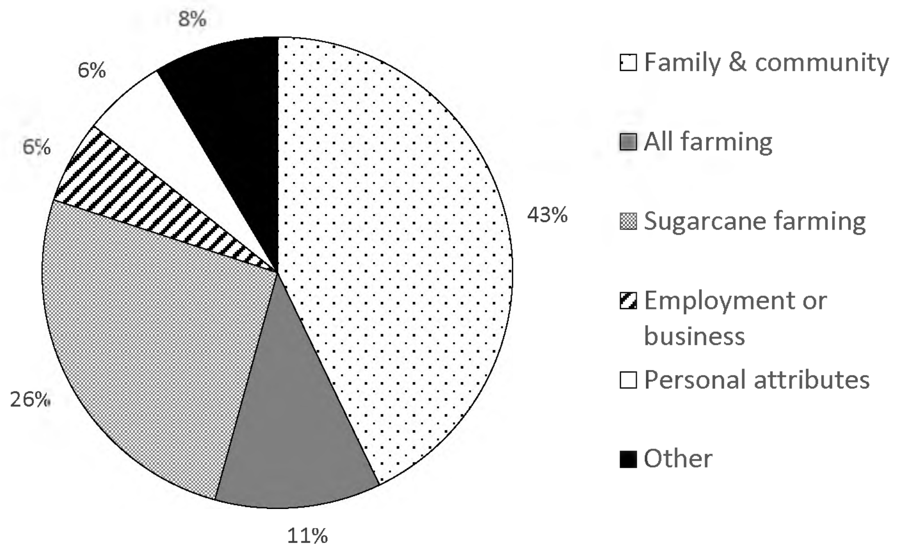


Figure 4.4. SSGs responses to the question "What allows you and your family to live in this area?" during individual interviews (n = 35).

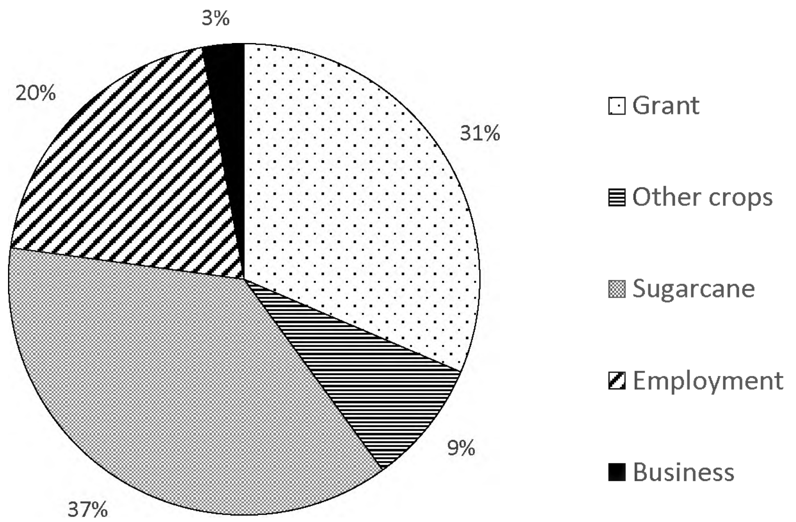


Figure 4.5. SSGs main source of income, as stated in the individual interviews (n = 35).

The main uses for sugarcane money include food for the family (31 %) and education for the children living in the household (26 %). It is interesting to note that a few farmers (11 %) reinvest most of the money that they earn from sugarcane back into the crop (Fig. 4.6). This shows that crop improvement is recognised as an important activity amongst some SSGs within the area. Other major expenses include household needs, building, transport (listed as 'other' in the graph) and reinvestment into other food crops (listed as 'other' in the graph) (Fig. 4.6). A relatively low number of SSGs (6 %) earn enough money from sugarcane to invest most those earnings into savings accounts (Fig. 4.6).

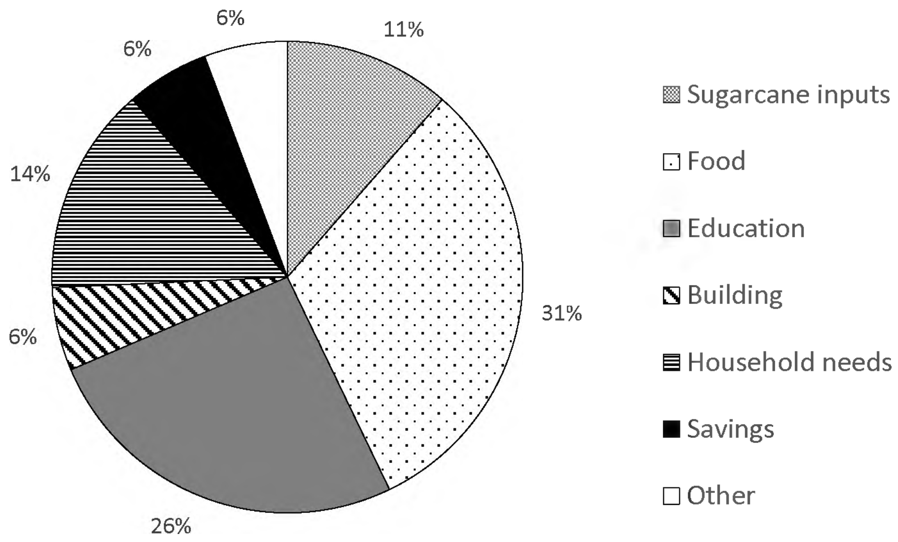


Figure 4.6. SSGs main uses for money earned through sugarcane production, as stated in the individual interviews (n = 35).

Qualitative quotes and data recoded during the individual interviews corroborate the quantitative data displayed above. Sugarcane is not only seen by SSGs as a means of getting by, it is also seen as means to improving their livelihoods through financial growth and the development of support structures for the future generation.

> *"Sugarcane is important. My whole farm is important. It gives me money to buy the things I need. It gives me food. Without it I could not raise my children or send them to school."*

> *"My pension helps me to live, but it does not improve our lives. Sugarcane does that. With sugarcane, I have made my house bigger and I can support my children and grandchildren."*

> *"My farm is where I live, it is my work and my income, and it feeds my household. My farm is my life. Without it and without sugarcane, where would I be?"*

These quotes emphasize the importance of sugarcane within the lives of SSGs. They also indicate that sugarcane is not the only important crop grown by SSGs. All farming activities and enterprises play an important role in the lives of SSGs by providing food, income, employment and stability within the community. This suggests that successful rural agricultural development in this area relies on faming as a whole, and not just sugarcane farming alone. SSGs also highlighted the benefits of farming over other forms of income or employment.

> *"I am a lucky man. My land is good and fertile. I can farm sugarcane and grow food and I don't have to work away from home. Sugarcane is my job, it is hard work, but I am my own boss and I can make my own decisions."*
>
> *"I work from home. I can look after the young children and I don't have to pay for day care or transport to work, these things make a big difference.*
>
> *"Why work and earn money for someone else? My sugarcane money goes into my own pocket"*

4.3.1.2. Sketch Maps

Four SSG illustrations were chosen as examples to confirm the role of sugarcane within the livelihoods of the farmers (Fig. 4.7). The areas shaded in grey indicate sugarcane fields and the English names of crops have been added to the maps (Fig. 4.7). The sketch maps show that farmers often grow more than one field of sugarcane (pictures A, B & C) and that sugarcane takes up a greater part of the land available to them for farming enterprises (Fig. 4.7). In cases where SSGs had only planted one sugarcane field (Picture D), the field was found to be larger or equal in size to other agricultural endeavours (Fig. 4.7). The sketch maps also demonstrate the diversity of farming strategies employed by farmers and the numerous crops that they rely on to secure their livelihoods (Fig 4.7).

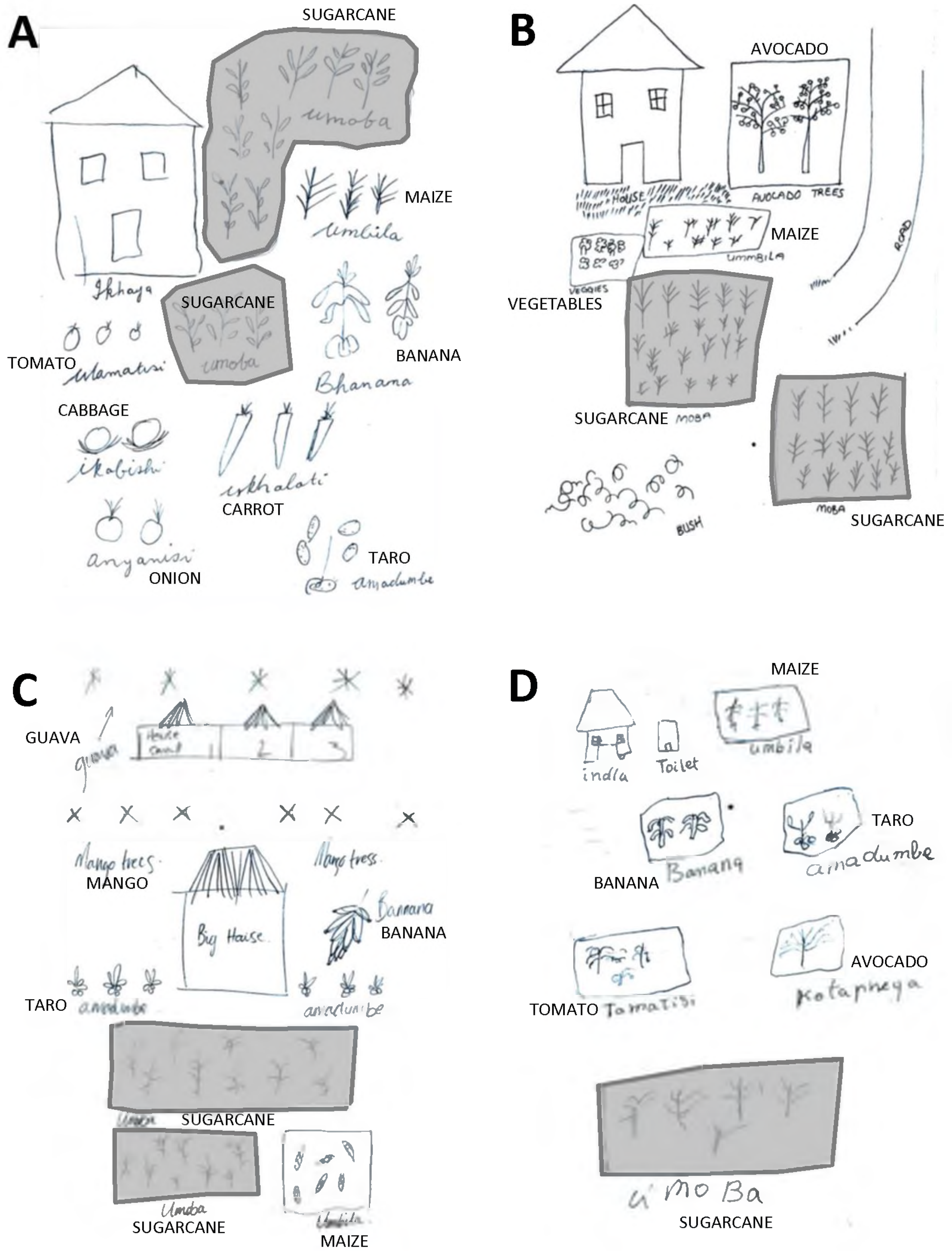


Figure 4.7. Four sketch maps drawn by different SSGs, which illustrate their households and farming systems and various agricultural enterprises.

4.3.1.3. Results from participatory matchstick matrix

For the participatory matchstick matrix, participants were asked to list their top five agricultural enterprises. Many SSGs listed more than five enterprises, saying that it was hard for them to separate the top five, since many of their crops are important contributors to their livelihoods. As such, the frequency distribution graph (Fig 4.8) bellow, depicts the full list of main agricultural enterprises as mentioned by the individuals interviewed. All farmers, except for one individual, listed sugarcane as an important crop within their livelihood strategies (Fig. 4.8). The farmer, who did not mention sugarcane as being an important agricultural enterprise, has only just planted the crop and has not yet profited from it. In addition to being the most frequently mentioned crop, sugarcane was also mentioned most often as first in the list of top agricultural enterprises (Fig. 4.8). This is reflected by the salience index. The salience index for sugarcane is 84.5 out of a possible 100 (Fig. 4.8). This is relatively high when compared to the salience index of the other farming activities mentioned, thus demonstrating the importance of sugarcane within the lives of the SSGs who were interviewed. The second most important crop was maize (SI = 53.1), followed by amadumbes (taro) with an SI of 34 out of 100 (Fig. 4.8). These data mirror the data collected by Cockburn (2013), who also found that sugarcane, maize and taro were the most important crops grown by SSGs in the Midlands North region of KZN. Banana (SI = 27.4), beans (SI = 25.9) and sweet potato (SI = 18.4) were the other important crops mentioned by the SSGs interviewed in this study. Cows (SI = 13.9) were the most important livestock farmed by SSGS, followed by chickens (SI = 7.8). The salience indexes of livestock are much lower than those of sugarcane or maize (Fig. 4.8), showing that such agricultural enterprises are considered as secondary ventures for SSGs.

For the matchstick matrix, only the first five agricultural activities listed by the SSGs were used to draw up the matrix. This was done to ensure that the exercise could be more easily replicated between participants. The variables used in the following analyses were divided between farming inputs and farming outputs. The input variables in this analysis were expenses for sugarcane (referred to as cane in Fig. 4.9 & 4.10), work effort (time and labour) for sugarcane, expenses for non-sugarcane farming enterprises (total), work effort for non-sugarcane farming enterprises (total), average expenses for non-sugarcane farming enterprises and average work-effort from non-sugarcane enterprises (Fig. 4.9). The output variables analysed from the matrix were income from sugarcane, food from sugarcane, income from non-sugarcane farming enterprises (total), food from non-sugarcane farming enterprises (total), average income from non-sugarcane farming enterprises and average food from non-sugarcane farming enterprises (Fig. 4.10).

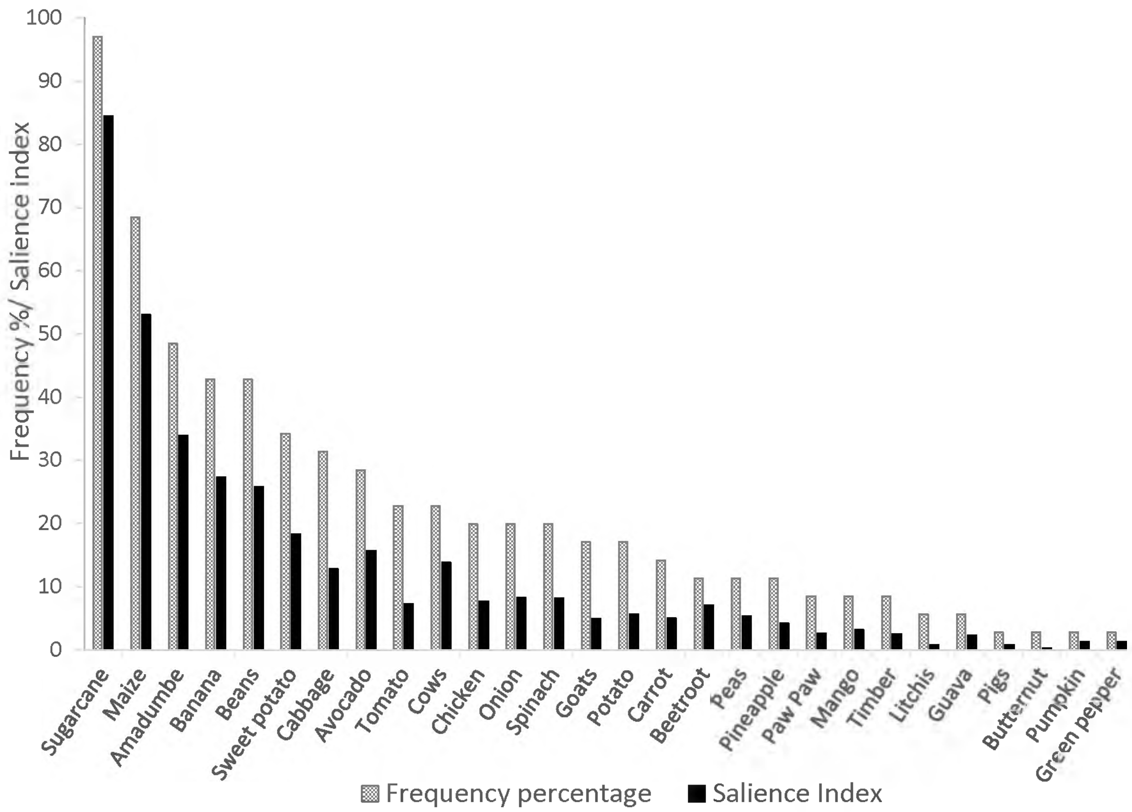


Figure 4.8. Frequency of mention (% respondents) and salience index (out of a maximum of 100) of the main agricultural enterprises as listed by SSGs during the individual interviews (n = 35).

The analysis of the matchstick matrix reaffirmed the importance of sugarcane within the livelihoods of SSGs. Sugarcane is considered the main agricultural enterprise pursued by SSGs. The sketch maps above showed that most the farmers' land is dedicated to sugarcane (Fig. 4.8). In addition to this, the matchstick matrix has confirmed that the farmers' concentrate their resources into the production of this crop (Fig. 4.9). Although total non-sugarcane enterprises cost farmers more to grow than sugarcane, sugarcane alone is considered the most expensive crop grown by farmers (Fig. 4.9). The average number of matches allocated per non-sugarcane farming enterprise is 7.85 (Fig. 4.9). In comparison, sugarcane expenses were ranked significantly higher by SSGs (27,37 matches) (Fig. 4.9). Similarly, although the total work effort spent on non-sugarcane enterprises is higher than the total work effort expended on sugarcane, when the work effort for non-sugarcane enterprises is averaged, then it is significantly less than the work effort put into sugarcane alone (Fig. 4.9).

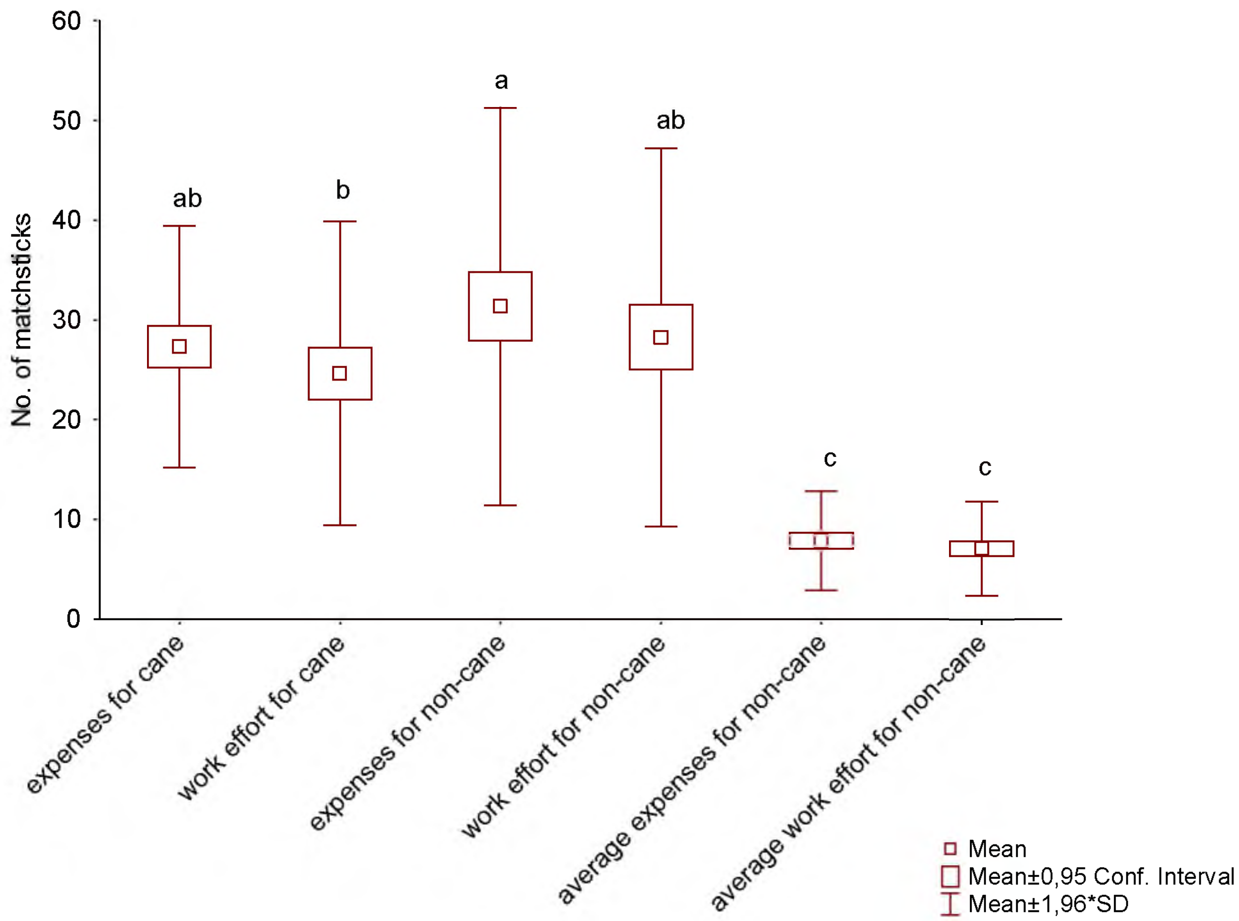


Figure 4.9. Box and whisker diagram showing the mean number of matches allocated to farmer inputs, across all agricultural enterprises, during the participatory matrix scoring activity (n = 35).

Farmer's not only dedicate a large portion of their resources towards sugarcane production, they also benefit economically from the crop. Sugarcane contributes greatly towards the financial security of SSGs (Fig. 4.10). SSGs use several strategies to make money, and many agricultural enterprises are used for income purposes (Fig. 4.10). However, a rank of farming outputs shows that income earned from sugarcane is greater than the total income earned from all other farming enterprises combined (Fig. 4.10). When other farming enterprises are looked at individually, we see that sugarcane generates significantly more income than any other non-sugarcane enterprise alone (Fig. 4.10). From these data, we can say that, in terms of monetary gains, other farming enterprises are viewed as secondary agricultural endeavours when compared to sugarcane production. From the graph, we can determine that non-sugarcane enterprises are more important as food crops (Fig. 4.10). Although income from sugarcane is used mainly to buy food (Fig. 4.6), total food gained from agricultural enterprises was ranked significantly higher than the food gained by growing sugarcane (Fig. 4.10). This is because, while SSGs do not make as much money from their individual non-sugarcane crops, they do use these enterprises to grow food for themselves and their household. Food crops and livestock are therefore used for subsistence purposes as well. This means that while sugarcane is used as the main cash crop, non-sugarcane agricultural enterprises are also important as commercial crops and provide SSGs with an alternative source of nourishment and nutrition. This highlights the importance of diversification within the rural agricultural sphere.

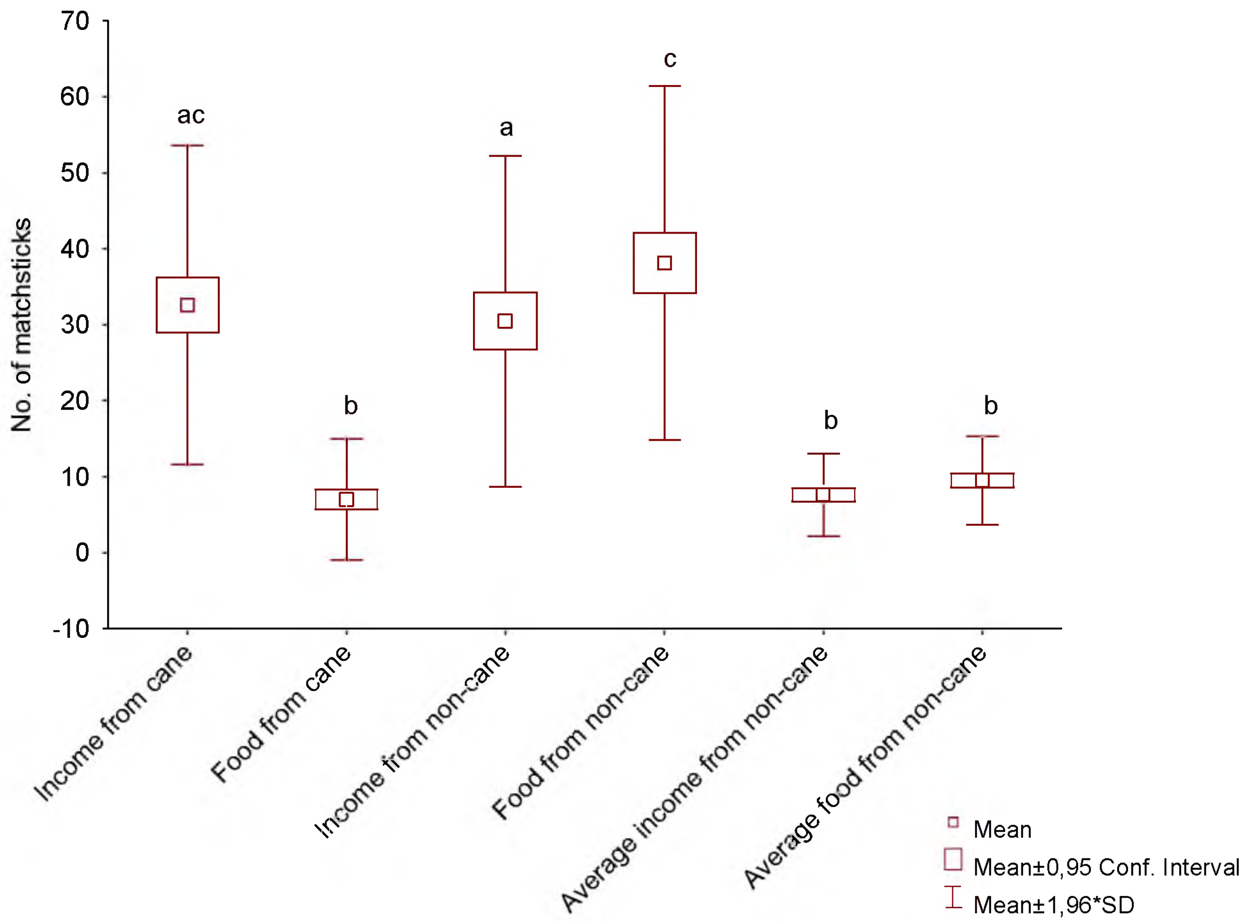


Figure 4.10. Box and whisker diagram showing the mean number of matches allocated to farmer outputs, across all agricultural enterprises, during the participatory matrix scoring activity (n = 35).

A table displaying the results of the ANOVA tests are located in the Appendix.

4.3.2 Sugarcane production constraints

The main sugarcane production constraint, according to coastal SSGs, are input costs (Fig. 4.11). In a free listing exercise, conducted during the individual surveys, 80 % of participants listed input costs as a major constraint (Fig. 4.11). The following quotes from SSGs shed some light on the types of input costs that impact their ability to make a living from sugarcane:

> *"Growing sugarcane is expensive, you must pay contractors and you must buy fertilizer, these things make it difficult to make a better income."*

"The transport costs are too high. You have to cut the cane and get it to the mill, by the time you are finished your profit is less"

"The money I get from sugarcane must be put back into sugarcane, if I don't do this then the sugarcane will not be good. The costs are high, but it is worth it"

With an SI of 54.4 out of 100, theft is considered almost as important as input costs (SI = 57,5) when it comes to sugarcane production constraints (Fig. 4.11). When asked further about the seriousness of theft, SSGs referred mostly to young people and passers-by, who take sugarcane to chew on, or who steal the stalks to sell on highways and in markets. SSGs were quick to point-out that theft was a farming constraint that did not only affect their sugarcane. It was also a major limiting factor when it came to the production of food crops. Farmers who were affected by theft considered it as one their most important constraints because they felt that there was nothing they can do to stop it from happening.

"I can water plants in the drought, I can fertilize the land, I can spray insects, but what can I do about the stealing? The people who steal do not know that it is important for my family. They are selfish. My fence doesn't work so there is nothing I can do. I must live with it"

It is interesting to note that insect pests are considered the third most important sugarcane production constraint (SI = 41) (Fig. 4.11). In comparison, Cockburn (2013) found that, SSGs from the Midlands North region, did not regard insect pests as a sugarcane production concern. SSGs in the southern coastal regions perceive pests as a major agricultural constraint, especially when it comes to financially important crops such as sugarcane (Fig. 4.11). As such, there is scope to develop alternative pest control techniques for small-holder farmers in this area.

Weeds are also perceived as a big problem for sugarcane farmers (Fig. 4.11). Weed control techniques should perhaps be included within the PPT framework to make it more attractive to farmers. Other important sugarcane growing constraints include environmental factors such as drought and land quality, and vertebrate pests such as monkeys, moles and livestock (Fig. 4.11).

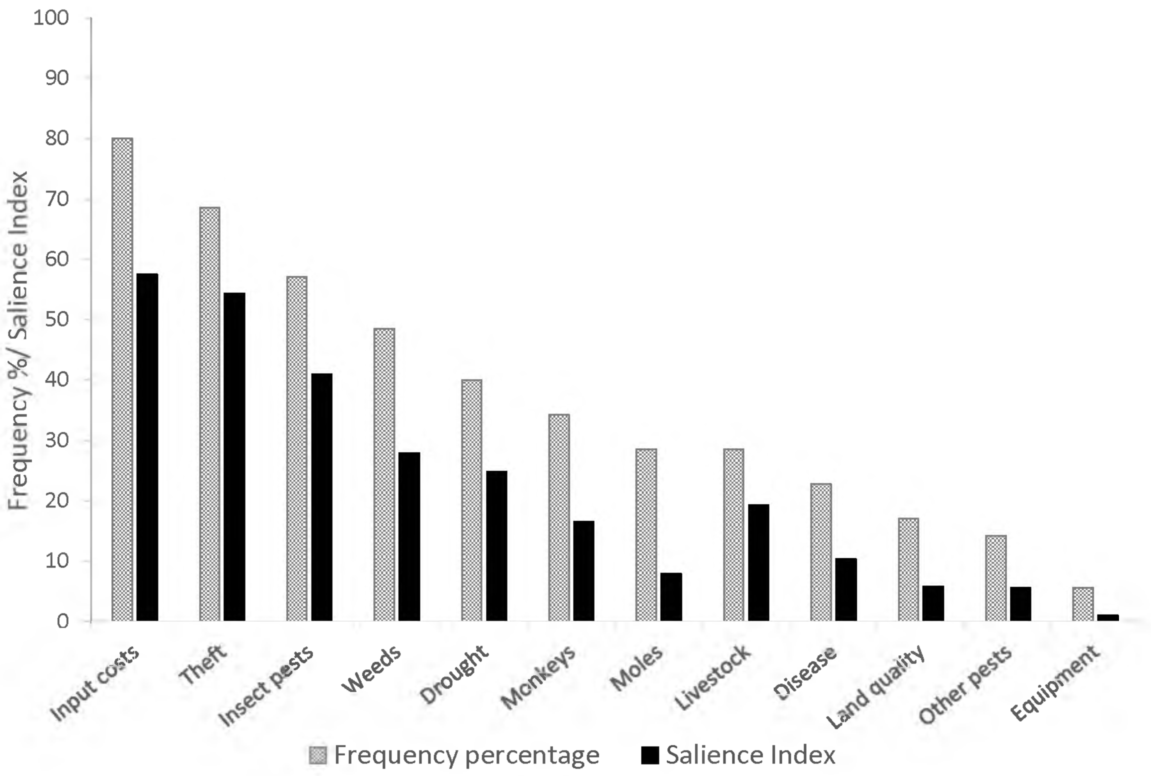


Figure 4.11. Frequency of mention (% respondents) and salience index (out of a maximum of 100) of the main sugarcane production constraints as listed by SSGs during individual interviews (n = 35).

4.3.3. Knowledge surveys

The pest and pest control knowledge surveys done during the individual interviews show that, on average, southern costal SSGs have a relatively good knowledge of the pests that attack sugarcane (Fig. 4.12). The mean pest knowledge score was 1.74 out of 3 (Fig. 4.12). This implies that most farmers could identify at least 2 pests, as well as describe them and discuss the type of damage that they cause to sugarcane (Midega et al. 2012). As a proportion of the total score, the pest knowledge exhibited by coastal SSGS was greater than the knowledge displayed by Midlands North SSGs (Cockburn 2013). Midlands North SSGs scored an average of 0.68 of 2 when asked about the type of pests found in sugarcane (Fig. 3.12 in Cockburn 2013). When the responses are looked at in greater detail, we see that a large portion of the farmers (62.9 %) recorded a medium to high knowledge score when questioned about sugarcane pests (Fig. 4.13).

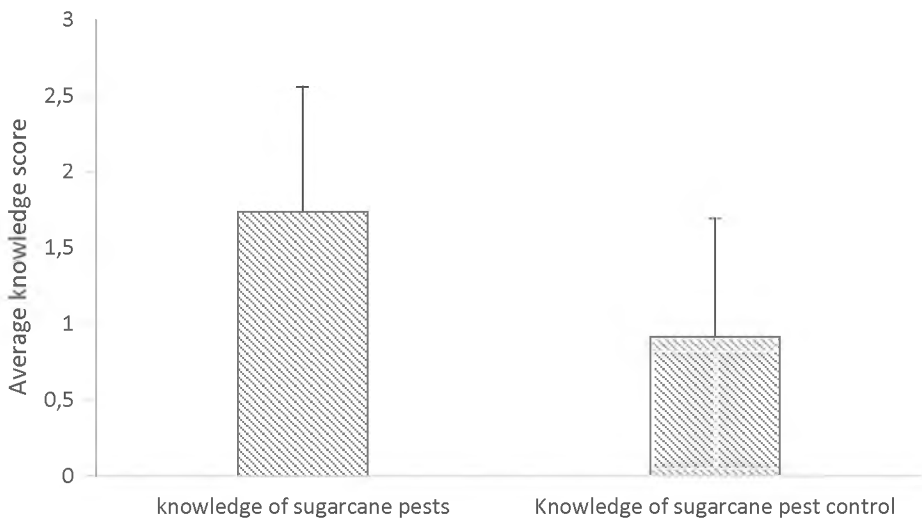


Figure 4.12. SSGs mean scores for knowledge of sugarcane pests and sugarcane pest control techniques (minimum score=0, maximum score=3). Bars indicate standard deviation (n = 35).

Even though farmers knew a lot about sugarcane pests, they seemed relatively uninformed about the types of control practices available to manage these pests in the crop (Fig. 4.12 & 4.13). Farmers scored an average of 0.92 out of 3 when asked about sugarcane pest control techniques (Fig. 4.12). This means that most SSGs could only discuss one type of control technique. In Figure 4.13, we see that an overwhelming number of the farmers interviewed (80 %) recorded a very low knowledge score when asked about sugarcane pest control techniques. In fact, over 30 % of the SSGs knew almost nothing about the different types of control practices available to them to combat the various pest of sugarcane (Fig. 4.13).

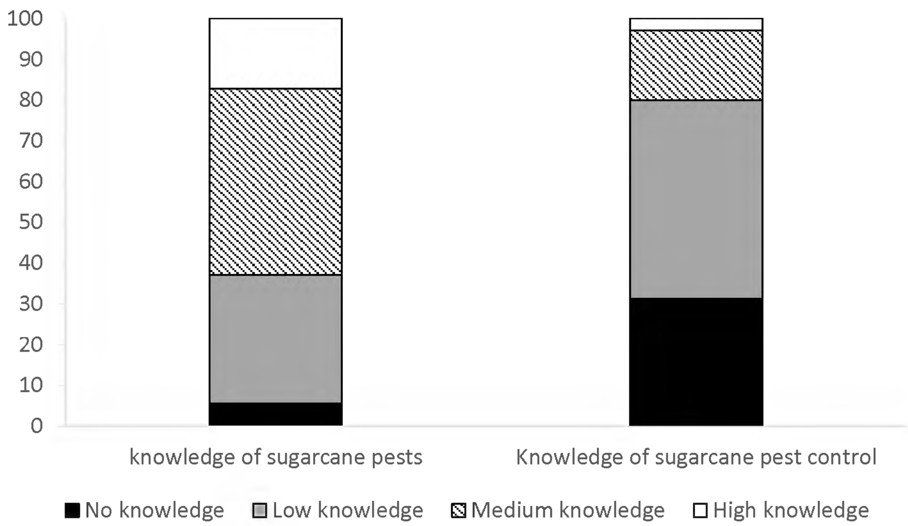


Figure 4.13. Frequency of respondents per knowledge category: no knowledge (score=0), low knowledge (score = 1), medium knowledge (score = 2), high knowledge (score =3) (n = 35).

4.3.4. Focus group discussions

4.3.4.1 Invertebrate free listing activities

The insects listed during the free listing activities can be seen in Table 4.3. SSGs were asked to draw up a list of the invertebrates that they have seen in sugarcane and to list any invertebrates that they considered as pests of sugarcane (Table 4.3). Four SSGs, out of the 58 individuals involved in the FGDs, chose not to participate in the free listing activities. The SSGs listed many invertebrates that are both beneficial and detrimental to farming and sugarcane production (Table 4.3). When asked specifically about pests of sugarcane, the SSGs listed several insects that are recognised by scientists as being pests of sugarcane, such as stem borers, termites, grasshoppers, scale insects, aphids, thrips, beetle grubs and leaf hoppers (Table 4.3). This helps to confirm that farmers from this area have a good understanding of the types of insect pests found in sugarcane. However, they also mentioned several invertebrates that are not harmful to sugarcane (Table 4.3). Some of these invertebrates are in fact beneficial to the crop, and act as natural enemies towards sugarcane pests. For example, ants and spiders were listed as sugarcane pests, however these invertebrates are known predators of insect pests such as stem borers (Table 4.3). This shows that there was a disconnect between insects that are perceived as pests by SSGs and invertebrates which are beneficial within the greater agroecosystem. Other invertebrates that were mentioned incorrectly as being pests of sugarcane were ticks. While ticks may be pests of livestock and carriers of disease, they are in no way harmful to sugarcane. For comparison purposes, SSGs were also asked about the types of pests that occur within their food crops (Table 4.3). From the table, it is evident that while SSGs are aware of sugarcane pests, they are more familiar with the different types of invertebrates that effect their non-sugarcane agricultural enterprises (Table 4.3). The list of food-crop pests is longer and there are fewer incorrect mentions (Table 4.3). This is likely due to the diversity of food crops grown and because type of damage sustained by food crops due to these pests is more visible and easily recognised.

A detailed analysis of the free lists show that stem borers (SI = 84,3) are considered the most important pests of sugarcane (Fig. 4.14). For analysis purposes, stem borers were grouped together because the SSGs refer to them using a wide array of common names. In most cases, a variety of isiZulu names were used when referring to stem borers. The most common names used when describing stem borers were inhlava, hlava, isihlava and isihlakava. *E. saccharina* was also referred to by its common name (eldana) a total of 23 times. *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae), another damaging pest on sugarcane, was identified using its common name (sesamia) 7 times. This means that, while farmers use generalized isiZulu names when discussing stem borers, they are aware of the different types of stem borers that attack their sugarcane and can identify the stem borers by species.

The following quotes demonstrate the ability of the farmers to recognise *E. saccharina* and the damage it does to sugarcane;

"You can tell when it is eldana in the sugarcane. When you cut open the stalks you can see that the sugarcane is red. Sometimes it is hollow at the bottom. If it is bad the stalk loses its strength."

"Eldana is easy to recognise. If you look closely, you can see the holes on the outside of the sugarcane. The flesh will be a red colour inside, and if you find the worm, you can tell that it is eldana if it moves backwards on your hand."

Other prominent pests of sugarcane, as mentioned by the farmers, include grasshoppers/locusts (referred to by the isiZulu name intethe), termites (referred to by the isiiZulu name umhlwa) and aphids (Fig. 4.14). It is important to note that farmers were provided with specimens and photos to better describe the insects they were listing.

Table 4.3. Three different lists of insects generated during FGD free-listing activities (n = 54).

Invertebrates that the SSGs have seen in sugarcane	Invertebrates which the SSGs consider as pests of sugarcane	Invertebrates which the SSGs have experienced as pests in their food crops
Stem borer	Stem borer	Snail
Aphid	Grasshopper	Aphid
Thrip	Termite	Grasshopper
Ant	Ant	Stem borer
Fly	Scale/ Soft scale	Cutworm
Scale/ Soft scale	Aphid	Ant
Moth/ Butterfly	Thrip	Beetle
Termite	Hairless caterpillar (other)	Hairy caterpillar
Beetle	Moth/ Butterfly	Moth/ Butterfly
Snail	Beetle grub	Leaf hopper
Fly	Tick	Fungus/ Mould
Grasshopper	Leaf hopper	Beetle grub
Spider	Spider	Slug
Tick		Scale/ Soft scale
Hairy caterpillar		Hairless caterpillar
Hairless caterpillar		Millipede/ Shongololo
Beetle grub		Spider
Earthworm		Fruit fly
Bee		Stink Bug
Wasp		
Leaf hopper		
Cutworm		
Lady beetle		

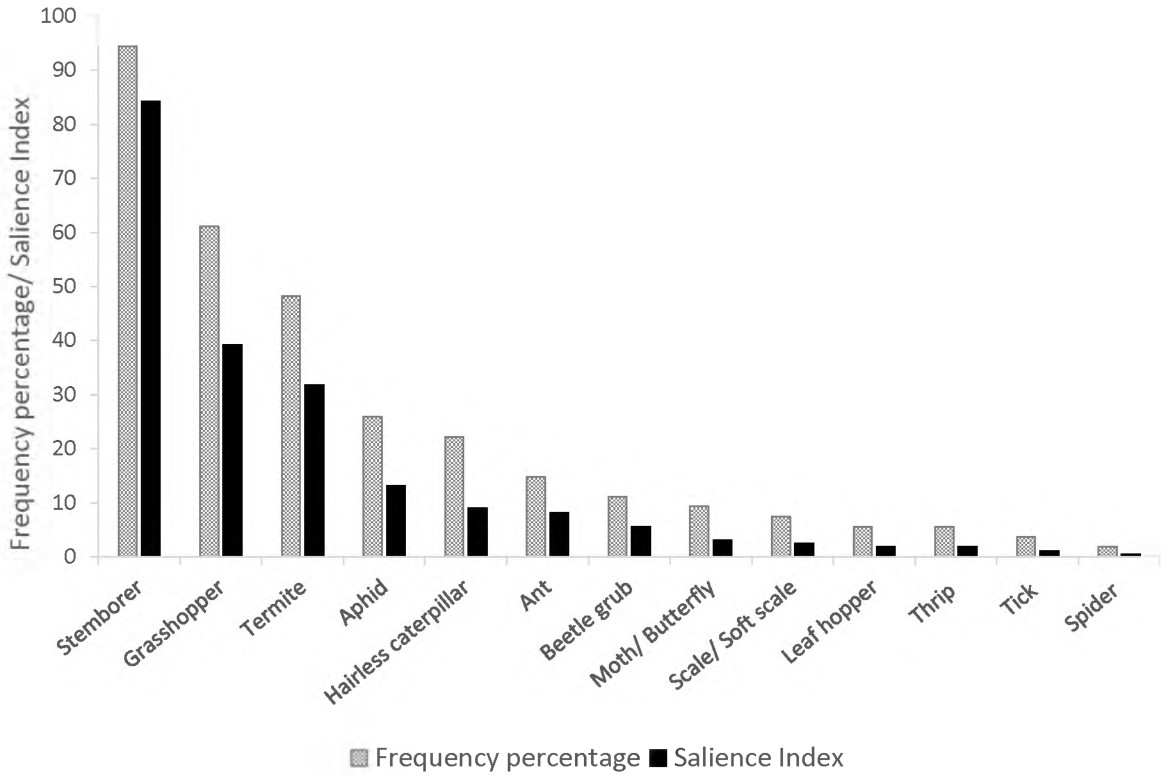


Figure 4.14. Frequency of mention (% respondents) and salience index (out of a maximum of 100) of the main sugarcane pests as listed by SSGs during FGDs (n = 54).

According to small-scale coastal farmers, the most important pest of their vegetables and food crops was cutworm (SI = 62.9). The next most important pests are beetles (SI = 44.5) and snails (SI = 40.2) (Fig. 4.15). These pests have a relatively high salience index when compared to pests of sugarcane (excluding stem borers) (Fig. 4.14 & Fig. 4.15). As in Cockburn (2013), vegetable pests seemed to be more common and more problematic than sugarcane pests. During the free listing activities, a total of 252 food crop pests were listed by SSGs, while only 168 sugarcane pests were mentioned.

It is unclear whether SSGs have a good understanding of insect biology. Moths and butterflies (bhebheshane in isiZulu) were listed as separate pests by some (Fig. 4.14 & Fig. 4.15), while others simply explained that the moths were adult stem borers/caterpillars. Similarly, it is hard to determine what the SSGs mean when they refer to hairless or hairy caterpillars (Fig. 4.14 & Fig. 4.15). They could be talking about specific insects or they could be using these descriptive terms as generalized names for pest which they are unable to identify. More detailed descriptions given by those SSGs who mentioned 'caterpillars' indicate that they could be referring to loopers, diamond back moths, bollworms, stem borers or cutworms. It was not always possible to gauge which insects they were talking about despite the availability of visual aids in the form of pictures and specimens.

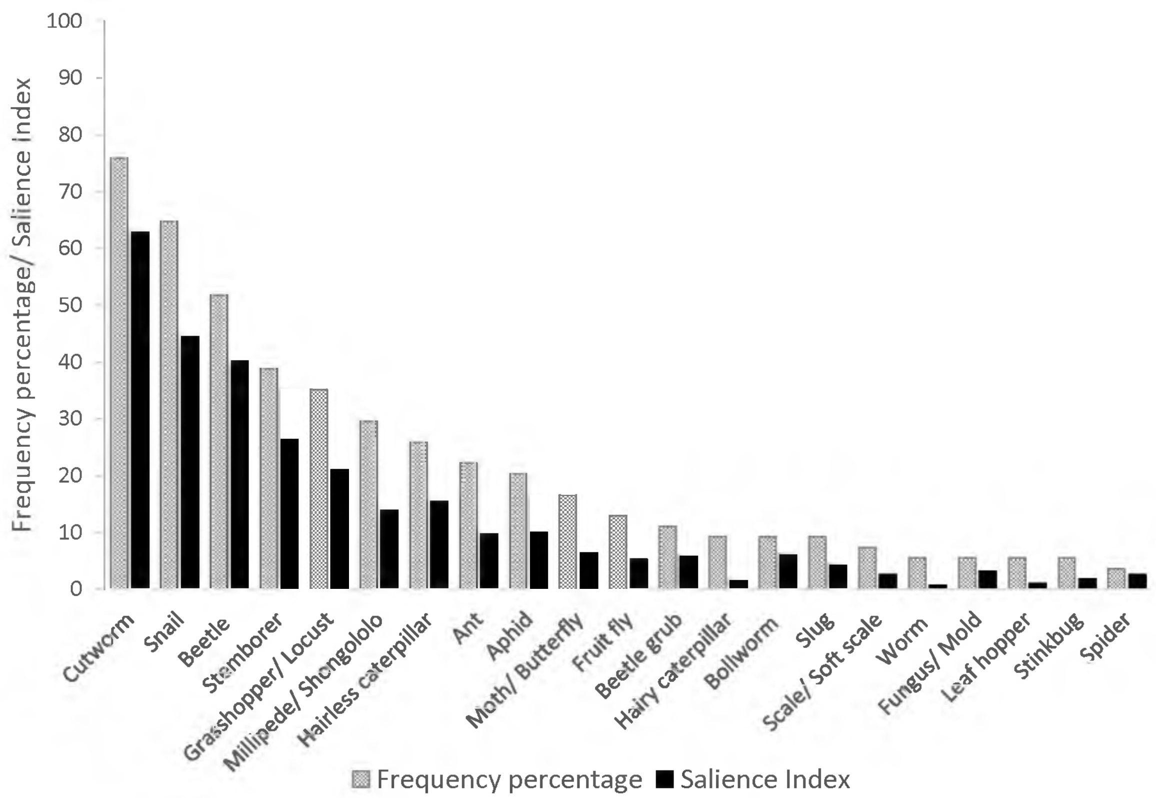


Figure 4.15. Frequency of mention (% respondents) and salience index (out of a maximum of 100) of the main food crop pests as listed by SSGs during FGDs (n = 54).

4.3.4.2 SSGs pest control strategies

Pest control strategies were openly discussed during the various FGDs. The findings of these discussions complement the findings of the free listing activities above, in that SSGs focused more on food crop pest control strategies than on sugarcane pest control strategies (Table 4.4). The frequency of mention of food crop pest control practices was 35, whereas the frequency of mention of sugarcane pest control practices was 16 (Table 4.4). There was also a strong emphasis on the use of chemicals to control crop pests (Table 4.4). Many SSGs mentioned using dichlorodiphenyltrichloroethane (DDT) as a form of pest control (Table 4.4). DDT has been approved for household use in some regions of South Africa to control malaria however, its use on crops has been prohibited (World Health Organization 2011, Coetzee et al. 2013). As such, it is likely that SSGs are not actually using DDT as a pest control mechanism. The name DDT is probably being used as a generalized term to refer to other chemical insecticides (Cockburn 2013). While chemical control mechanisms made up the bulk of pest management strategies, SSGs in the southern coastal regions discussed, and employed a variety of non-chemical, cultural and mechanical practices (Table 4.4).

SSGs focused more specifically on food crop pest control during the FGDs, however, many sugarcane pest control methods were also discussed (Table 4.4). Although it has been determined that SSGs lack information regarding sugarcane pest control strategies, they are aware of some practices that have been recommended as techniques that improves pest management in sugarcane (Table 4.4). The most popular sugarcane pest control strategy among SSGs is early harvesting. A farmer at one of the FGDs was recorded describing the benefits of early harvesting to other SSGs.

"It is a bad thing to leave the sugarcane in the field for too long. This is when the eldana comes. If you cut the sugarcane a little bit earlier, then the pests do not have time to attack the sugarcane."

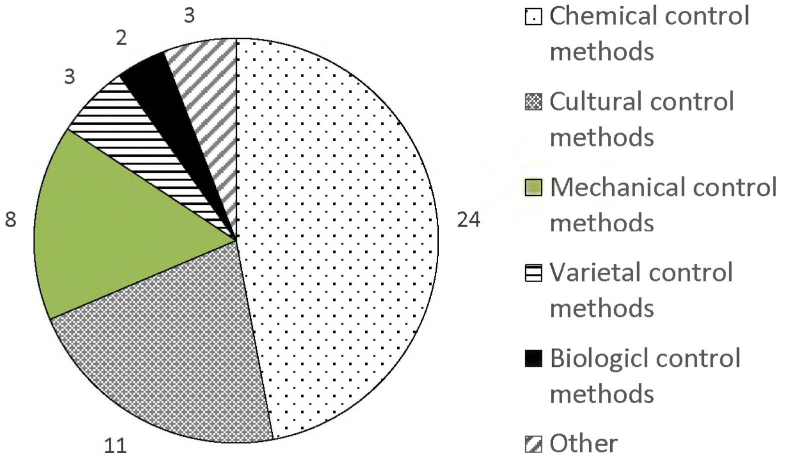
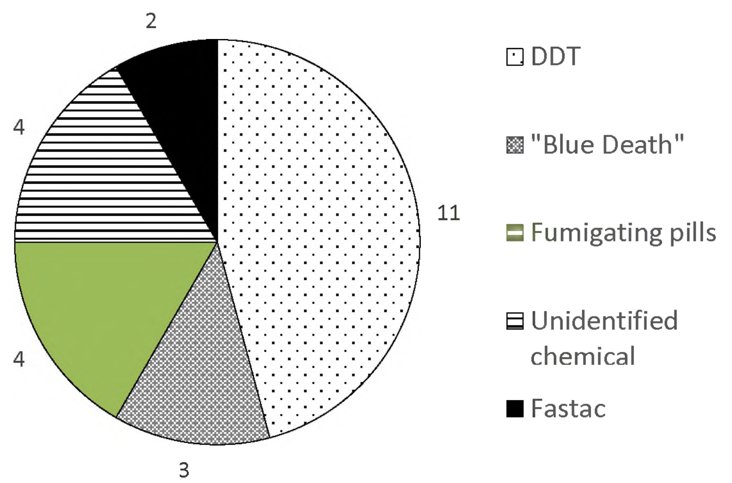
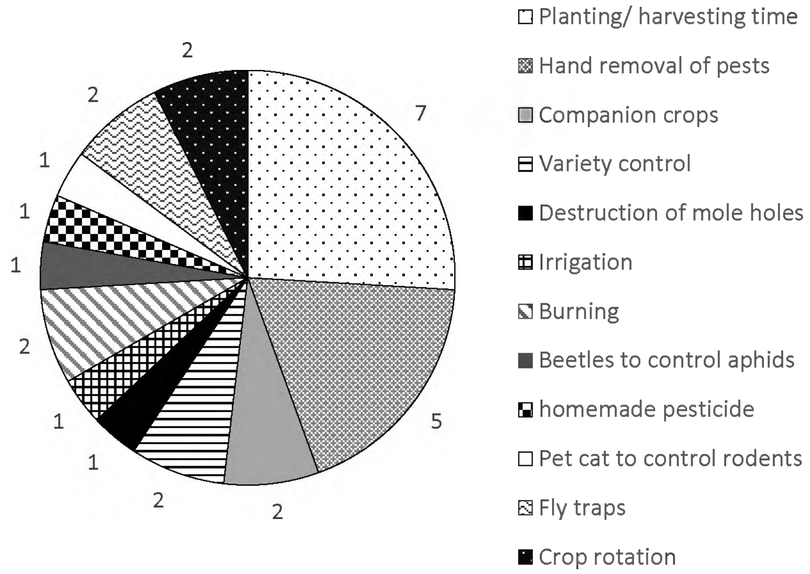
Varietal control was recognised by 2 SSGs as being an important pest control technique for sugarcane (Table 4.4). However, these SSGs also said that they did not know very much about the different types of sugarcane varieties and they felt that they did not have access to improved varieties. Most SSGs reportedly grow N12, which is a relatively hardy and drought resistant variety of sugarcane (SASA 2006). Burning before harvesting was also discussed by SSGs as a pest control technique, and one SSG even mentioned irrigation as means of preventing stemborer attacks (Table 4.4).

"During a drought the stem borers are worse. I have heard that irrigation can stop pests from attacking the sugarcane. Water makes the sugarcane healthy. When the sugarcane is healthy the pests cannot get into the stalks and damage the crop."

This information shows that SSGs in the coastal regions generally know more about sugarcane pest control strategies than those in the Midlands North sugarcane growing regions of KZN (Cockburn 2013).

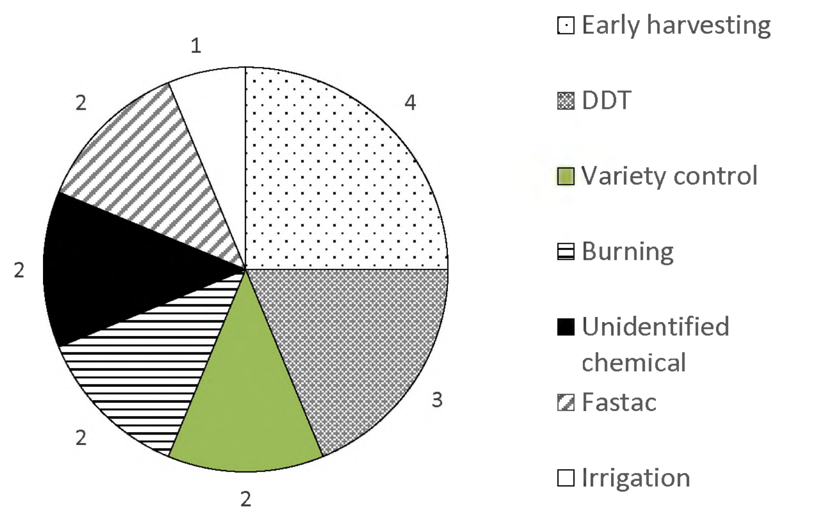
When asked about food crop pest control during FGDs, almost half of the responses (49 %) referred to chemical control mechanisms (Table 4.4). Nevertheless, SSGs also use non-chemical strategies to control pests in their vegetable crops (Table 4.4). A few SSGs (5) practice the mechanical removal of pests by hand, while others practice cultural control methods to reduce pest infestations (Table 4.4). The manipulation of planting and harvesting times to avoid peaks in pest populations is a cultural control mechanism that was mentioned by farmers (Table 4.4). The rotation of crops and the planting of companion plants are further examples cultural control mechanisms that are used by SSGs (Table 4.4).

Table 4.4. Summary of quantitative content analysis of focus group discussions on pest control in SSGs sugarcane fields and food crops (n = 58).

Topic	Summary of findings	Pie chart to illustrate frequency of mention of categories within each topic
General pest control	Pest control was mostly discussed for food crop pests. There is a strong emphasis on chemical control, however, South Coast SSGs do know about other methods of pest control.	
Chemical control	DDT was mentioned most frequently during discussions about chemical control methods. Fastac, a chemical used specifically against *E. saccharina* and other stem borers, was mentioned by name by 2 of the South Coast SSGs.	
Non-chemical control	SSGs are aware of and employ a number of non-chemical pest control methods. Cultural control methods, mechanical control methods, varietal control methods and biological control methods were discussed. SSGs manipulate planting and harvesting times to avoid peaks in pest populations. This strategy was deemed the most important non-chemical pest control method.	

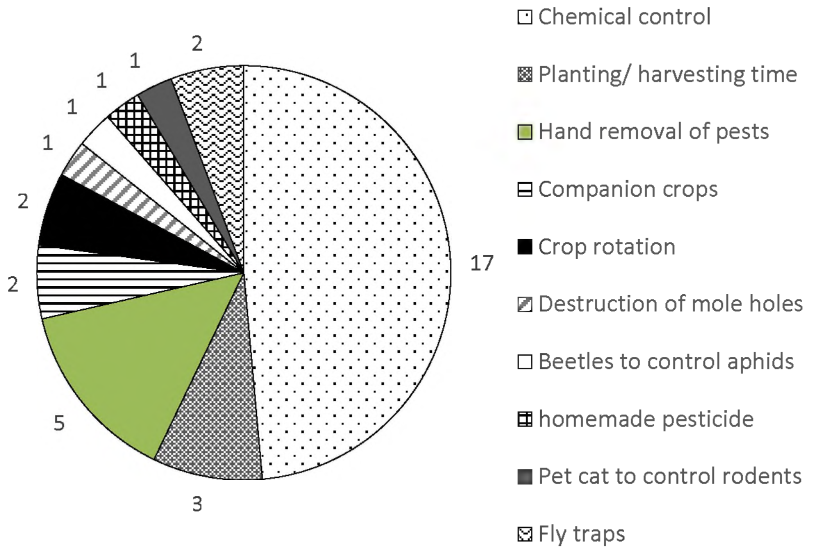
Control of sugarcane pests

Unlike SSGs in the Midlands North, small-scale farmers on the South Coast were able to discuss different control techniques for pests in sugarcane. Early harvesting and pesticides were mentioned most frequently as pest control strategies in sugarcane. Other well-known and recommended pest control tactics were also mentioned including varietal control and irrigation.



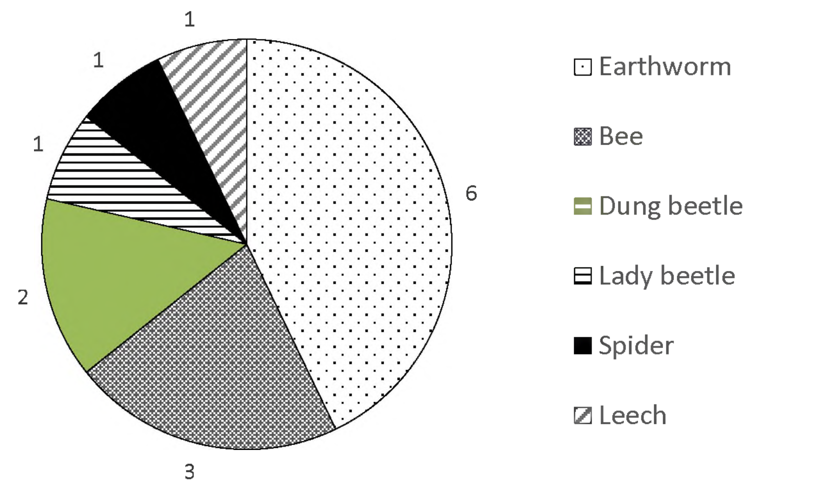
Control of food crop pests

SSGS were able to talk more easily and freely about different control tactics employed against pests in food crops. Although chemical controls were once again mentioned most often, a variety of other pest control methods were mentioned and discussed. Small-scale farmers in this region use a diverse range of farming practices to protect their food crops from damage.



Beneficial insects

The majority of SSGs struggled to think of insects that are beneficial to them and their farms. Although they are not insects, earthworms were mentioned most frequently in this category. Only two people mentioned predatory invertebrates (lady beetle and spider) and discussed how they help to reduce crop pests.



One SSG stated that chemicals were too expensive for her family and as such, she creates her own homemade pesticide to use against food crop pest.

"I make my own pesticide. It is cheaper and easier to do it this way. I boil water and add chillies and garlic. When the water has cooled, I put it into a bottle with ash and sunlight soap and sometimes a little bit of vegetable oil. I spray this on the plants to stop the pests."

Due to the high costs and erratic supply of chemical pesticides, it is not unusual for small-scale rural farmers to adopt homemade, alternative and organic pesticides to deal with their pest problems (Poswal and Akpa 2008). SSGs also resort to using attractants and traps to lure pests away from their fruit trees and ultimately kill them (Table 4.4). Two SSGs even mentioned using biological control mechanisms to help control pests on their food crops (Table 4.4). One SSG owns a cat, which she says keeps the rats and mice out of her vegetables (table 4.4). Another SSG said that beetles can be used to stop the aphids feeding on tomatoes and cabbages (Table 4.4). Most SSGs believe that all insects are detrimental to their crops. However, after discussing predatory beetles, it was evident that there is some recognition of the role that beneficial insects can play in pest management. Beneficial organisms were mentioned 14 times during the FGDs (Table 4.4). Although not all the organisms mentioned were insects, it is encouraging to note that some SSGs appreciate that invertebrates can be beneficial to their farms and the surrounding environment. From a pest management perspective, only two beneficial organisms were mentioned (Table 4.4). It is therefore likely that SSGs lack a true understanding of the role that predation and parasitism play in management of pest populations.

Summary of interpretations and lessons learnt from insect FGDs:

- SSGs perceive sugarcane pests as a serious production constraint.
- Stem borers, particularly *E. saccharina*, are considered important pests of sugarcane.
- SSGs have problems with insect pests on food crops.
- SSGs know more about food crop pest control practices than sugarcane pest control practices.
- SSGs rely primarily on chemical control measures to control pests, but some farmers do know about alternative pest management strategies.
- SSGs generally perceive insects negatively, and do not know about beneficial insect predators and parasitoids.

4.3.4. Push-pull workshop

During the workshop SSGs expressed a keen interest in push-pull and its ability to manage pests within the sugarcane agroecosystem. They were particularly interested by the push-plant *Melinis minutiflora* and its insect repelling and weed suppressing properties. The SSGs also showed enthusiasm when told that *M. minutiflora* could be used to protect both maize and sugarcane. The fact that molasses grass can be used as livestock fodder and that it does not need a lot of water was also a pertinent selling point for the SSGs. Most of the questions were directly related to the planting of Molasses grass (common name for *M. minutiflora*) and its growth. And a total of 5 farmers asked if they could have the *M. minutiflora* plants that were bought to the workshop for demonstration purposes. The following statements taken from the workshop demonstrate the interest in this plant.

This molasses grass can get rid of stem borers and stop the weeds from getting into the sugarcane? This is a good thing. I spend a lot of money getting sprays and labour to control the weeds. If this grass works, then I can use that money elsewhere.

If I can get this plant I no longer have to spend lots of time weeding on my farm.

How must I plant this grass, must I put it in the sugarcane or on the outside and how often must I water it? If you give me some molasses grass I can grow it myself, then I won't need to worry about stem borers in my sugarcane and in my maize.

It is two birds with one stone. I get to stop the pests in my crops and feed my goats at the same time. It is like a miracle grass.

Unfortunately, SSGs did express some reservations when it came to the implementation of a push-pull programme for the control of *E. saccharina* in sugarcane. SSGs had major misgivings with regards to the cost of push-pull. 46 SSGs said that they would adopt PPT is they were shown how to use it and if the plants were made freely available. In contrast, only 8 SSGs said they would still use PPT if they had to put some money into it.

My costs are already too much. This push-pull sounds good, but where is the proof. I don't want to pay money to do something that is not promised to work for my farm.

The statement above highlights the importance of 'proof'. It is necessary for researchers and extension officers to set up demonstration plots and to perhaps arrange for some trials to be conducted on SSGs farms to fully determine whether PPT will work in this area. Without concrete evidence of success, it is doubtful that SSGs will invest resources into the adoption of push-pull for sugarcane. SSGs also expressed doubt as to whether or not the pull-plants will work on their farms. The main pull-plants used in the South African sugarcane push-pull programme are wetland sedges. These sedges, in the genus *Cyperus*, generally require wet habitats to grow. Many SSGs worry that they do not have the water capacity on their farms to ensure the proper growth of these plants.

But my farm has no stream or water, these plants will die, and they will not trap any stem borers.

Alternative pull-plants will be needed if PPT is to be promoted in small-scale areas. Additional training courses and field days will also be required to teach the farmers about these IPM practices. Although farmer seem keen to use push-pull, they agreed that they would like the extension officer to dedicate more time to explaining it. They also said that demonstration plots are a useful tool and that if push-pull trials were successful they would be willing to adopt the technology.

4.4. Discussion

4.4.1. The role that sugarcane plays in SSGs livelihoods and farming systems.

It is obvious from the data collected here that sugarcane plays a significant role in the lives of SSGs on the South Coast and Lower South Coast of KwaZulu-Natal. Farmers perceive sugarcane as their main source of income and they rely on sugarcane to buy food, support their families, improve their households and gain access to education for their children. SSGs also dedicate large portions of their land to sugarcane and invest many resources into the production of this crop.

Although sugarcane is regarded as the most important crop grown by SSGs, it is by no means the only agricultural enterprise pursued by small-scale farmers in this area. SSGs livelihoods are supplemented through many other activities and enterprises. From the individual interviews, it is evident that SSGs engage in a wide range of diverse livelihood strategies. Netting (1993) found that small-scale famers generally produce a significant portion of their own subsistence. They also contribute towards the market by selling their agricultural goods and by partaking in other, off farm, employment opportunities (Netting 1993). Similarly, SSGs grow a variety of other food crops to eat and to sell at local markets. They also keep livestock, engage in business activities, seek employment and collect government grants to enhance their income and improve their food security. Diversity in livelihoods strategies amongst small-holders is recognised elsewhere, and studies report that rural based farmers often engage in multiple agricultural and financial enterprises as a means of improving household income (Ellis 1998, Neves and du Toit 2013). This is supported by the evidence collected in Cockburn (2013), which showed that Midlands North SSGs also employed a diverse array of farming and non-farming activities.

The participatory matchstick matrix showed that, while SSGs grow wide variety of crops, sugarcane alone generates significantly more income than any other agricultural enterprise. The value of sugarcane in the rural communities of sugarcane growing regions has been well documented by several other authors (Armitage et al. 2009, Eweg et al. 2009, Hurley and Sibiya 2011, Nothard 2011, Cockburn et al. 2014, Eweg 2005, James and Woodhouse 2015, Ntshangase 2016). However, detailed, mixed methods studies, such as these, can contribute towards a better understanding of SSGs farming methods and how they use sugarcane as a part of an integrated farming system (Cockburn 2013). By opening up a dialogue between scientists and SSGs, we have discovered that farmers rely heavily sugarcane for financial stability, with additional crops providing food and an alternative means of making money. Diversification allows for an increase in prosperity and improves resilience during times of hardship (Bryceson 1999). Farmers also depend on their families and surrounding communities to maintain their farms and to live in the southern coastal areas. The allocation of land through tribal authorities means that individuals with strong historical, familial and community ties to the area are more likely to have access to farming land (Makhanya and Ngidi 1999, Agergaard and Birch-Thomsen 2006). By unpacking the fundamentals of SSGs livelihoods, farmer participatory research can help to solve problems that are more closely related to farmers' individual conditions (Bellon 2001, Gonsalves et al. 2005). An increase in the impact of agricultural research and the wide-spread adoption of new agricultural technologies can be achieved by first addressing the small-scale farmers' specific wants and needs (Bellon 2001).

Sugarcane not only improves the financial prospects of farmers in impoverished areas, but also provides important employment opportunities to rural communities and contributes to the overall growth and sustainability of the sugarcane industry in South Africa (Eweg 2005). As such, it is important that SSGs are provided with increased institutional support, and advice, in order improve production output (Armitage et al. 2009). Coordination and communication between multiple stakeholders, including farmers, tribal authorities, millers, training and extension services, contractors and researchers, can help to address some of the SSGs farming constraints (Eweg 2005).

4.4.2. Sugarcane production constraints

According to data collected during the individual interviews, input costs are the biggest sugarcane production constraint faced by SSGs. Farmers must pay for planting, fertilizer, harvest and transportation contractors and labour. Furthermore, communal land distribution means that many famers own small plots of land (1-4 ha) that cannot support enough sugarcane to simultaneously cover production costs and make a substantial living (Mahlangu and Lewis 2008, Eweg 2005). A lack of land ownership also results in a lack of collateral and SSGs struggle to secure loans/funding for equipment and labour (Makhanya and Ngidi 1999, Agergaard and Birch-Thomsen 2006). Therefore, famers must rely on contractors whose services are often unreliable and expensive (Nothard 2011, Armitage et al. 2009).

In the past, SSGs were developed, subsidised and supported through sugarcane milling companies (Dubb 2015). Furthermore, millers facilitated and oversaw the planting, plant establishment, ratoon management, harvesting and transportation of sugarcane on smallholdings in rural sugarcane growing regions (Dubb 2015). A financial funding scheme that was run by the sugarcane industry also ensured that farmers were provided with loans to help them buy equipment and farming inputs such as fertilizer (Dubb 2015). Training schemes, additional extension services and increasing representation within the industry drew more small black farmer into commercial sugarcane production (Dubb 2015). However, the deregulation of the sugarcane industry lead to a dramatic decrease in the subsidies offered to small-scale growers (Dubb 2015). Milling companies withdrew technical and institutional support, and, due to increase in opportunism, fraud and debt, the SSG financial funding scheme was forced to close its credit facilities (Armitage et al. 2009, Dubb 2015). The abandonment of the Two-tiered quota payment system, the declining profitability of sugarcane and severe droughts further reduced the economic squeeze on small-scale farmers (Nothard 2011, Armitage et al. 2009, Dubb 2015). As such, SSGs, while recognised as independent sugarcane producers, have been left under-capitalised and sorely constrained by the mounting costs of sugarcane production (Dubb 2015).

In addition to high input costs and dwindling returns, SSGs are faced with issues such as theft and the destruction of sugarcane by cattle and goats (Jones and Singels 2015, Murray 2010, Dubb 2013). Theft was named as the second most important constraint faced by farmers in the southern coastal regions of KZN. The loss of crops through theft, though random and sparse, happens frequently in rural areas. For farmers who already suffer from small landholdings and reduced incomes, stealing is an added burden that has a meaningful impact on an already depleted production output. Farmers are also demoralised by incidences of theft because they feel that there is little that they can do to prevent people from stealing, not only from their sugarcane, but from their food crops as well.

Pests and weeds were also recognised as significant production constraints by the SSGs. Research has found that sugarcane yield declines in Southern African are partly due to increasing pest and weed pressures (Fanadzo et al. 2010, Jones and Singels 2015). Weed control takes up a large portion of smallholders farming efforts including time, labour and financial inputs (Labrada et al. 1994, Fanadzo et al. 2010, Dubb 2013). Cockburn (2013), found that weeds were ranked as the top economic constraint by SSGs in the Midland North region of KZN. It was recommended that extension officers prioritize weed control in this area (Cockburn 2013). Weeds are widely recognised as a major constraint to small-scale sugarcane and crop production in Sub-Saharan Africa (Fanadzo et al. 2010, Gouse 2012, Muzari et al. 2012, Dubb 2013). In contrast, relatively little is known about the true yield impacts caused by pest infestations in small-scale grower's crops (Abate et al. 2000, Goebel et al. 2005, Fanadzo et al. 2010, Van den Berg 2013).

Goebel et al. (2005), showed that pest surveys were skewed towards the large-scale sector, with little to no data available on the prevalence of pests in SSG communities. Several articles state that stemborer infestations are generally lower in SSG sugarcane (e.g. Atkinson and Carnegie 1989, Way et al. 2003, Goebel et al. 2005, Cockburn 2013). Small-scale farms have a higher level of vegetational diversity than large-scale monoculture sugarcane and SSGs generally harvest sugarcane earlier than their large-scale counterparts (Goebel et al. 2005). This prevents the build-up of pests within SSGs crops (Gontier et al. 2003). In addition to this, Midlands North growers did not perceive insect pests as a sugarcane production constraint (Cockburn 2013). However, this does not mean that pests do not play an important role in yield deficiencies in other regions of the country. SSGs in the southern coastal regions identified insect pests as their third most important production constraint after input costs and theft. Insect pests were also listed as a major production constraint by SSGs interviewed in Mtubatuba on the North Coast of KwaZulu-Natal (Dubb 2013). Although SSGs in the coastal regions have expressed their concerns over insect pests, it is unclear whether such pests cause significant losses in crop yields. Clearly more work needs to be done on the distribution of insect pests in the small-scale sugarcane growing regions of South Africa. The extent of insect damage done to smallholder crops should also be quantified so that researchers, extension officers, farmers and other stakeholders can act accordingly to mitigate future losses. If insect pests are a priority concern, IPM and push-pull technology have the potential to reduce infestations and improve small-scale sugarcane outputs and profit margins.

4.4.3. SSGs perceptions of pest and pest control

SSGs knowledge of sugarcane pests is relatively good, with many respondents receiving high scores when asked about pests during the individual interviews. This is reflected in the FGD free listing and group discussion activities. SSGs listed many known insect pests of sugarcane, discussed sugarcane pests freely within the group setting, and could identify many sugarcane pests correctly. This supports the findings that pests are considered a production constraint by SSGs, since farmers know about sugarcane pests and can readily recognise them. Previous studies, focusing on farmers knowledge and perceptions of pests, have found that well-known pests are often the pests that cause the most damage or else are extremely prevalent within the famers fields/crops (Chitere and Omolo 1993, Bottenberg 1995, Arshad et al. 2008). Stem borers were perceived to be the most damaging pest of sugarcane. Although SSGs use generalized isiZulu names to refer to all stem borers, some famers were able to single out *E. saccharina* as the most abundant of the damaging sugarcane pests. Another sugarcane stemborer, *S. calamistis*, was also mentioned by name several times. Other prominent pests mentioned by SSGs include grasshoppers or locusts, termites and aphids.

The farmers demonstrated a high-level of knowledge when it came to sugarcane pests, however, some SSGs also mentioned beneficial invertebrates as being pests on sugarcane. Some of the organisms mentioned, such as ants and spiders, act as predators in sugarcane agroecosystems (Carnegie et al. 1981). These invertebrates reduce populations of stem boring insects and other pests in sugarcane fields (Carnegie et al. 1981, Leslie 1981, Webster et al. 2005, Way et al. 2006). The fact that some SSGs view these beneficial organisms as constraints, shows that there is a lack of knowledge of ecological processes and a lack of understanding regarding the roles that various invertebrates play within the environment (van Huis and Meerman 2009). It is widely acknowledged that farmers are often unaware of the beneficial actions of natural enemies (Abate et al. 2000, van Huis and Meerman 2009, Midega et al. 2012). This is evidenced here. While a few SSGs could name beneficial invertebrates, only two individuals mentioned predatory invertebrates, which are able to reduce pest populations. No parasitoid insects were mentioned.

According to the knowledge scores, the SSGs are unfamiliar with the different types of pest control mechanisms that can be used to manage pest populations in sugarcane. Farmers in the Midlands North also had a poor understanding of crop protection practices (Cockburn 2013). Thus, there is a need for extension and advisory services to continue concentrating on pest management practices to educate SSGs on the variety and application of pest and disease control strategies (Armitage et al. 2009, Cockburn 2013, Eweg 2005). A recognition of insect pests does not automatically result in efforts to improve control mechanisms, especially amongst resource poor farmers (Chitere and Omolo 1993). High inputs and low returns mean that farmers are often unable or unwilling to put time and money into crop improvement strategies (Mahlangu and Lewis 2008). While SSGs know about some control practices, they do not want to learn more about these practices, or invest resources into applying their knowledge, because they feel that the benefits gained through improved management techniques is not worth the effort (Mahlangu and Lewis 2008). Access to education, training, low-input technologies and incentives could help to increase the adoption of sugarcane crop protection strategies (Mahlangu and Lewis 2008, Eweg 2005). During the FGDs, the farmers did discuss a few different pest management techniques for pests in sugarcane. They mentioned using varieties, burning, early harvesting and chemicals as pest control techniques. One SSG even mentioned irrigation as a means of reducing *E. saccharina* infestations. Overall southern coastal SSGs have a better understanding of sugarcane pest control tactics than Midlands North SSGs. However, many SSGs were still unsure about when to use different control tactics or how they work. Demonstration plots, which are employed as an extension tool in SSG areas (Gillespie, *et al.* 2009, Gillespie, *et al.* 2012), could be used to better explain the various control techniques and their benefits. Improved varieties should also be made more accessible to Small-scale growers.

It is evident that SSGs perceive food crop pests to be a greater farming constraint than sugarcane pests. During FGDs a greater number of food crop pests were mentioned. Cutworms, snails, beetles and grasshoppers/locusts were the most important food crop pests mentioned by SSGs. Free listing activities also revealed that the SI of food crop pests was generally higher than sugarcane pests. It is therefore unsurprising that SSGs prioritise pest control on their food. Food crop pest control techniques were discussed at length, and a greater variety of food crop control mechanisms were mentioned. Many SSGs reported using pesticides against food crop pests. In Africa, growing population pressures, modernization and demands for increased productivity have increased the use of chemical pesticides (Abate 2000, Dinham 2003, Naidoo et al. 2010). Unfortunately, inadequate regulation, outdated legislation, poor literacy rates and a dearth in education and training results in the indiscriminate use of pesticides amongst smallholder communities (Naidoo et al. 2010). Product selection, application rates and timing are often poor, and farmers frequently spray too often (Dinham 2003). The result is that farmers, their families and the wider community are at risk of exposure and adverse health effects, particularly since resource poor farmers often lack the capital to invest in the necessary protective gear (Naidoo et al. 2010). The types of risks faced by SSGs is unclear, however SSGs have reported mixing chemicals by hand, using unknown chemicals, and storing chemicals within the household. This is problematic since many of the insecticides used on vegetables in developing countries, such as organophosphate and carbamate pesticides, are acutely toxic (Dinham 2003, Naidoo et al. 2010). Training in IPM and the harmful effects of pesticides can help small-scale farmer to become better decision makers, and hopefully reduce the dangerous and indiscriminate use of pesticides (Dinham 2003).

4.4.4. Push-pull and SSGs farming systems

Smallholders employ complex farming systems that are well adapted to the local conditions and sustainably managed to meet subsistence needs (Altieri et al. 2012). Although there has been an increase in chemical use amongst small-scale African farmers, due to lack of credit, these farmers typically farm without mechanization, fertilizers, pesticides, or other technologies of modern agricultural science (Altieri et al. 2012). This means that natural enemy abundances within small-scale farming communities are typically conserved and can be exploited as biological control agents against pests (van Huis and Meerman 1997). Smallholders also regularly practice inter-cropping, crop rotation and substitute monocultures for diversified agricultural landscapes (Altieri et al. 2012, Khan et al. 2014). This is typical of the SSGs farming systems. Diverse farming systems, intercropping, crop rotation, low chemical inputs and natural enemy conservation are all practices which fit easily into an IPM framework. As such, SSGs are well-suited to adopt and implement IPM technologies.

As an IPM strategy that also promotes sustainable farming and BMPs, push-pull is a useful tool to improve sugarcane yields by promoting pest management and habitat diversity. SSGs in the southern coastal regions have highlighted pests as a major constraint and have singled out stem borers as the most damaging pests on sugarcane. As such an IPM tool like push-pull would be suitable for farmers in this area. During the push-pull workshops, farmers expressed a keen interest in PPT. Several farmers took *M. minutiflora* home with them to plant around their sugarcane fields. They also wanted to know how to grow and propagate the plant themselves. This is encouraging as it shows that the SSGs are actively willing to try push-pull and other new technologies. Unfortunately, IPM programmes are characteristically complex and knowledge intensive (Altieri 2002). Farmers need to have a good understanding of the interactions between plants and pests and other environmental factors that influence these relationships (Altieri 2002). To employ IPM techniques farmers also need to acquire good problem solving and decision-making skill sets (Matteson 1992, van den Berg and Jiggins 2007). It is therefore important that farmers receive proper training through demonstration plots, farmer field schools and workshops if push-pull is to be successful (Matteson 1992, van den Berg and Jiggins 2007). In Kenya, small-scale maize farmers exposed to field days and other extension methods were more likely to adopt push-pull (Kahn et al. 2008a). These same farmers also rated push-pull as being far superior to other pest management practices and attributed PPT to higher maize yields (Khan 2008). The success of PPT in Kenya was achieved by directly addressing farmer's production constraints (Khan et al. 2008b). Researchers did not focus solely on maize production outputs, but tailored the technology to suite the smallholders' entire farming systems (Kahn et al. 2008b). The push-pull programme in Kenya has improved food security, household income and rural development in the region (Kahn et al. 2014), as such it can serve as a model to improve the livelihoods of SSGs in South Africa.

Melinis minutiflora is an important component of the sugarcane push-pull program. It is able to repel stemborer pests and ticks, attract beneficial natural enemies, supress weeds and it can be used as fodder for livestock (Prates et al. 1998, Barker et al. 2006, Conlong and Campbell 2010, Khan et al. 2010). SSGs rely on a large assortment of farming enterprises to supplement their monetary and household needs. An IPM programme that improves the production of multiple crops is more likely to be accepted by SSGs. The fact the *M. minutiflora* is able to protect both sugarcane and other food crops from weeds and stemborer attack was an important talking point during the PPT workshops. The SSGs were similarly interested in the fodder potential of *M. minutiflora*. These characteristics of *M. minutiflora* could be used as potential marketing tools to promote the adoption of PPT amongst small-scale farmers.

A vital component of successful IPM systems is the development of technologies that suite the farmer's needs and economic constraints (van Huis and Meerman 1997, van den Berg 2013). This is especially true of small-scale farmers in Africa, who are often reluctant to adopt technologies that are unfamiliar, complicated, potentially unsuited to their diverse farming systems and not guaranteed to provide meaningful financial returns (Barret et al. 2002, Dercon and Christiaensen 2007). Although the SSGs in this study seemed partial towards the adoption of PPT, they had some reservations concerning the plants used in PPT and the cost of the technology. Wetland sedges, such as *C. dives* and *C. papyrus*, are used as the pull component of the sugarcane push-pull programme. However, many of the small-scale farmers expressed reluctance regarding the use of wetland sedges. Most farmers agreed that they lacked appropriate wet areas on their farms, and they doubted whether the sedges would grow properly. In Kenya, the push-pull system used *Pennisetum purpureum* Schumach (Poales: Poaceae) as a stemborer trap crop (Khan et al. 2010). This plant could be used as an alternative to wetland sedges. In South Africa *Bt*-maize is also used as an additional pull-component in areas where sedges cannot be planted (Keeping et al. 2007), however *Bt-maize* is expensive, and it is not always accessible to small-scale growers (Gouse 2012). It is important that a suitable alternative trap crop be found, which is better suited to SSGs farming systems. Smallholder farmers were also reluctant to say whether they would pay money towards the implementation of PPT on their farms. Successful push-pull demonstrations would help farmers commit to PPT, but it is likely that some form of subsidisation would be needed if PPT is to be promoted in SSG areas.

4.5. Conclusions and Recommendations

The focus of this project was to gain an understanding of SSGs farming systems and the role that sugarcane plays within SSGs livelihoods. This was done to determine whether BMPs and IPM techniques could be used as a means of increasing sugarcane production, household income and food security amongst smallholders. Despite low yields and high input costs, sugarcane was found to be a major contributor towards SSGs livelihoods. BMPs, IPM and improved extension services are effective tools for addressing some of the farming constraints that are affecting sugarcane yields. BMPs and IPM can be used to increase the income of farmers by optimising yield, they can also be used to improve business and management practices and even reduce the cost of sugarcane inputs. However, the financial constraints faced by SSGs are complex and not solely linked to poor production outputs. Improved management techniques, while useful, are unlikely to erase the difficulties generated by credit constraints, poor institutional structures, contractor inefficiencies, land discrepancies, theft and opportunism bought on by an unequal system. If farming practices are to be effectively improved and the sustainability of small-scale sugarcane production enhanced, the challenges experienced by SSGs need to be holistically addressed through institutional collaboration, improved stakeholder communication and industry regulation. The results from the interviews confirm that pests are perceived as a major threat to production. As such, PPT is recommended as a useful tool for the control of *E. saccharina* and other sugarcane and maize stem borers in this area. *M. minutiflora* is also recommended as a source of food for livestock and as a means of reducing weed infestations. The enthusiasm expressed by the farmers clearly demonstrates that push-pull would be well received by SSGs, however, the technology needs to be adjusted to suite the farming system of these growers. Furthermore, this study merely served as an exploratory analysis. Further participatory studies and larger sample sizes are needed to discern the role that IPM can play within the community. Researchers also need to quantify the damage caused *E. saccharina* to truly understand whether PPT will financially benefit South Coast and Lower South Coast sugarcane growers.

Chapter 5

General Discussion

5.1. Introduction

In chapter 1, the importance of sugarcane as a primary agricultural commodity in South Africa was discussed. *Eldana saccharina* was singled out as the number one pest of sugarcane in South Africa and its effects on the sugarcane production were highlighted as a major constraint to sugarcane farmers and the growth of the industry as a whole. Pest management tools for the control of *E. saccharina* in sugarcane were also discussed and the need for sustainable methods of pest management were recognised. The use of push-pull as a component of AW-IPM was established as an effective strategy for the control of *E. saccharina*. Push–pull is as stimulo-deterrent diversionary strategy that exploits plant derived semio-chemicals in a manner that repels insect pests away from a crop, whilst simultaneously attracting them into trap crops, or other habitats within the agroecosystem (Hassanali et. al. 2008). Push-pull has been successfully implemented in East Africa, where it is being used to control populations of lepidopteran stem borers in cereal crops (Khan and Pickett 2004). Building on the work done in East Africa, and research focusing on the biology and ecology of *E. saccharina* and its indigenous host plants, scientists at SASRI developed a push-pull programme for the control of this pest in South African sugarcane (Kasl 2004, Barker 2008, Conlong and Rutherford 2009, Webster 2009). This programme has proven effective in managing infestations of *E. saccharina* in the Midlands North sugarcane growing region of South Africa (Cockburn 2013, Conlong et al. 2016). However, adoption of push-pull in other sugarcane growing regions has been poor.

This study aimed to facilitate the implementation of push-pull for the management of *E. saccharina* in sugarcane in the coastal sugarcane growing regions of KwaZulu-Natal, South Africa. These areas were chosen for the study because the economic losses caused by *E. saccharina* in the coastal sugarcane growing regions is typically high when compared to other sugarcane growing regions in South Africa (Goebel et al. 2005). Four objectives were identified, which collectively worked towards providing evidence of the efficacy of push-pull whilst simultaneously improving the current working model of push-pull to better suit the needs of sugarcane farmers in this area. The outcomes of these four objectives are discussed in the sections below. The conclusions of this study, and recommendations for further research into push-pull and IPM development for the sugarcane industry, are covered in the closing sections of this chapter. Additional information regarding this study, and the results of statistical tests conducted in each of the previous chapters can be found in the Appendix.

5.1.1. Objective 1 - Assess the efficacy of push-pull for the management of *Eldana saccharina* in the coastal sugarcane growing regions of Kwa-Zulu Natal, South Africa

Since most of the previous work done on push-pull for the control of *E. saccharina* has been conducted in the Midlands North sugarcane growing region of KZN, it was necessary to conduct trials along the coastal sugarcane belt to determine if push-pull was a suitable pest management strategy in this area. Furthermore, sugarcane farmer's in the coastal regions wanted proof of the efficacy push-pull before they were willing to implement it (see chapter 3). Therefore, in chapter 2 push-pull trials were set up on five model farms along the coastal sugarcane growing belt of KZN. Two model farms were located in the North Coast sugarcane growing region, and three model farms were located in the South Coast sugarcane growing region. Here the effects of push-pull on populations of *E. saccharina* were monitored in the sugarcane as well as in rehabilitated wetland areas.

The results in chapter 2 showed that push-pull was effective at controlling *E. saccharina* at four of the five model farms chosen for on-farm field trials. The percentage of stalks showing stem borer damage, and the number of *E. saccharina* larvae found within sugarcane decreased significantly after push-pull was implemented on these farms. This provides evidence that if implemented correctly, push-pull is able manage infestations of *E. saccharina* in coastal sugarcane growing areas.

The results from the fifth push-pull trial at the Glen Rosa model farm were less conclusive. Here the populations of *E. saccharina* increased slightly in both the push-pull and control sites. However, *E. saccharina* numbers at Glen Rosa were much lower than those found at the other four sites. Previous studies have found that the efficacy and cost-benefits of push-pull increase in areas that suffer from high *E. saccharina* pest pressure (Barker et al. 2006, Barker 2008). The results from Glen Rosa confirm these findings. Since the coastal sugarcane belt of KZN have some of the highest *E. saccharina* numbers recorded in sugarcane fields throughout the sugarcane industry (Singels et al. 2016), growing *M. minutiflora*, in conjunction with a 'pull' component, stands to provide real financial benefits to farmers in this region. This is particularly true of farmers who are forced to cut their sugarcane at 12 months to avoid an increase in *E. saccharina* infestations and damage in older sugarcane (Ramburan et al. 2009). A significant decrease in *E. saccharina* due to push-pull may allow these growers to keep their sugarcane in the field for longer periods of time. Research has shown that even a slightly longer cropping cycle can increase profits by improving the sucrose content of the sugarcane (Inman-Bamber 1991, Bezuidenhout et al. 2002, Ramburan 2015).

As part of the push-pull trials on selected model farms, water courses and wetland habitats were rehabilitated through the removal of sugarcane from these areas, and through the transplantation of indigenous wetland sedges. Sedges that act as natural host plants for *E. saccharina* and other stem borers were chosen for transplantation. Surveys in transplanted stands of *C. papyrus* and *C. dives* demonstrated the effectiveness of these 'pull' plants in attracting *E. saccharina*. Furthermore, several parasitoids were found emerging from *E. saccharina* larvae that were collected from these sedges. Wetland areas serve to increase the biodiversity of an agroecosystem, providing natural habitats for stem borers and acting as reservoirs for stemborer parasitoids (Moolman et al. 2012). Therefore, wetlands provide an important pest management function within farming habitats in addition to other ecosystem services such as water conservation (Altieri and Nicholls 2004, Kotze et al. 2007). This is further highlighted with data from the Glen Rosa and Ellingham Estates model farms. At these two sites, extremely high populations of *E. saccharina* were found in *C. dives* in comparison to sugarcane, indicating that the sedges are acting as a sink for *E. saccharina* and not a source of infestation. These findings are in support of Cockburn (2013), who recommended the conservation and proper maintenance of wetland habitats on sugarcane farms.

5.1.2. Objective 2 – Develop a working model for the implementation of push-pull in the North and South Coast sugarcane growing regions of Kwa-Zulu Natal, South Africa

This study achieved the successful implementation of push-pull on coastal model farms, using the working model of push-pull as developed by Cockburn (2013), with input from Kasl (2004), Barker (2008) and Barker et al. (2006). The effectiveness of the push-pull trials as described in chapter 2, demonstrates that the above-mentioned working model provides and adequate framework for the management of *E. saccharina* using PPT. However, based on input from model farmers, and other farmers interviewed in chapter 3, the following considerations have been highlighted.

Firstly, *Bt*-maize was deemed too costly and time consuming to use as a push-pull plant by the farmers of this project. It is a useful, but not a vital component to the success of PPT and it is likely that most coastal farmers would opt not to use *Bt*-maize as part of a push-pull system (see chapter 3). Therefore, further studies into the use of alternative push-pull plants are needed. This is especially necessary because the pull plants, *C. dives* and *C. papyrus*, can only be grown in low-lying or wet areas, and these are not always available to sugarcane farmers, who might wish to implement push-pull management. This is further emphasized in chapter 4, where small-scale sugarcane growers expressed concern regarding the use wetland sedges in push-pull systems, since many of these farmers do not have water courses or wetland areas near their farms.

Although the results in chapter 2 demonstrate the efficacy push-pull, there was also variability in the data collected from within and between push-pull sites and control sites. Different fields and farms experience different conditions, and site-specific factors must be taken into consideration when adopting IPM strategies (Barzman et al. 2015). This is an indication of the knowledge intensive nature of technologies such as PPT. Cockburn (2013) discussed the importance of variety choice, ratoon cycles, harvesting dates, and good crop management practices in the successful implementation of push-pull, thus highlighting the necessity of using push-pull as a component of a broader IPM framework. Practices such as the injudicious use of pesticides, poor varietal control, and burning before harvest can jeopardise the effectiveness of PPT. For example, the burning of sugarcane reduces the abundance of important natural enemies of *E. saccharina* (especially ants, earwigs and spiders) within the sugarcane agroecosystems (Leslie and Boreham 1981, Webster et al. 2005). Because PPT relies on the conservation of natural enemies as a form of pest suppression, area-wide reductions in predators can lead to a resurgence of stem borers in sugarcane fields despite the implementation of push-pull and other pest management technologies (Landis et al. 2000, Cook et al. 2007). It is also imperative that farmers time the planting of push-pull plants correctly (Cockburn 2013). *Eldana saccharina* moth peaks typically occur in April and November (Carnegie and Leslie 1990). Push-pull needs to be working efficiently before these moth peaks if farmers want to prevent oviposition in their sugarcane. *Melinis minutiflora* takes approximately 6 months to establish, and farmers should take this into account, and plan push-pull systems well in advance of moth peaks, in order to protect their sugarcane (Cockburn 2013).

Drought conditions were experienced in the sugarcane growing regions of KZN throughout the duration of this study (Singels et al. 2015, Singels et al. 2016). Although M. minutiflora is a drought tolerant species, poor rainfall affected the growth and establishment of this grass at a number of the push-pull model farms (chapter 2). However, a high percentage establishment and cover abundance of *M. minutiflora* was achieved when farmers watered the plants every 2-3 days for approximately 4 weeks after it was planted. *Melinis minutiflora* seedlings were also planted with AQUA STOR KM™ which was used to retain water around the roots of the seedlings. These methods are recommended for farmers who wish to plant *M. minutiflora* in the dry season and during times of below average rainfall.

Although PPT was able to reduce damage and infestation to manageable levels at some of the farms, it is still not advisable to age sugarcane using only this method. Fastac® is still recommended for farmers who wish to carry over their sugarcane from December to April. However, it is important to remember that push-pull systems work best as long-term pest management solutions (Landis et al.

2000). The goal of habitat management is not only pest control, but also the creation of a suitable ecological infrastructure within the agricultural landscape, that is spatially and temporally beneficial for the crop, indigenous habitat and natural enemies of the pest (Landis et al. 200). Judging from the success of PPT over one season, if it is correctly maintained and used in conjunction with other sound IPM practices, it could, over time be used as a mechanism to age sugarcane. Improved results can be obtained when push-pull is used in conjunction with other Integrated pest management methods, such as continuous surveys, soil and nutrient management, good varietal control, harvesting schedules, crop rotation and further wetland rehabilitation (Cockburn 2013, Rutherford 2015).

5.1.3. Objective 3 – Determine large-scale sugarcane growers' knowledge and perceptions of *Eldana saccharina,* IPM and push-pull, and explore the drivers and barriers of adoption of push-pull

In chapter 3, large-scale sugarcane growers in the North and South Coast regions demonstrated a good basic knowledge of *E. saccharina*, and the conventional pest management techniques used to control this pest. Although many farmers had heard of push-pull and IPM, they did not know how push-pull works or how to implement PPT on their farms. Furthermore, farmers requested proof of the efficacy and cost-benefit of push-pull. This demonstrates that farmers need to be provided with more information on push-pull before they are willing to adopt it. Whilst the efficacy of push-pull has been demonstrated in chapter 2 of this study, more research needs to be conducted regarding the economic advantages of push-pull. This would potentially offset any worries regarding the perceived risk of adopting IPM technologies (Khan et al. 2008a, Gent et al. 2011).

Farmers indicated that they would prefer direct contact with extension staff and LPD&VCC when learning about PPT so that they can voice their specific concerns about push-pull and its applicability to their own on-farm situations. This provides further evidence that the successful adoption of new pest management techniques relies on a multidirectional flow of information, and farmers need to be included in the development of IPM strategies to ensure that the strategies are useful to them (Leeuwis 2004, Klerx et al. 2012). A desire for field days, and experiential learning was also expressed. First-hand experience of IPM technologies, demonstration plots, participation in field-days and contact with other farmers employing new pest management strategies have been shown to increase the adoption of such strategies (Khan 2008a, Amudavi et al. 2009). Therefore, these methods can be used to improve the adoption of PPT amongst LSGs in the coastal sugarcane growing areas of KZN.

In Chapter 3 it was reported that almost 11% of farmers interviewed in the coastal regions have adopted some aspect of push-pull, however none had adopted both a push and a pull component. This was ascribed to the lack of understanding of how push-pull works and to the fact that most farmers did not know where to source push-pull plants. In the Midlands North, efforts by the LPD&VCC

to provide push-pull inputs, in the form of wetland sedges (*Cyperus* spp.), increased the rate of adoption of PPT in that area (Cockburn 2013, Conlong et al 2016). It is likely that the provision of push-pull plants in the North and South Coast sugarcane growing regions would have the same effect. Extension staff and LPD&VCC in these coastal regions should therefore consider developing nurseries of push-pull sedges and *M. minutiflora* as a resource for famers wishing to adopt PPT.

The ease of management and overall practicality of push-pull was questioned by LSGs, with the technology being perceived as a 'hassle' by some farmers in this study. This was also seen as a major barrier to the adoption of push-pull in the Midlands North sugarcane growing region (Cockburn 2013). Other barriers to adoption mentioned by North and South Coast LSGs include financial constraints, lack of institutional support, uncertain land tenure, and the negative attitudes of farmers towards sustainable agricultural practices. Unfortunately, not all these barriers can be addressed by researchers and extension staff at SASRI. However, the provision of incentives is seen as a means of overcoming some of the economic issues faced by farmers, which prevent them from adopting new pest management strategies (Rodriguez et al. 2008). Commitments by all involved parties to improving the collaboration and communication between researchers, farmers and industry stakeholders may also address some of the barriers mentioned above (Leeuwis 2004, Nederlof et al. 2007), thereby leading to increased uptake of PPT by sugarcane growers (Cockburn 2013).

5.1.4. Objective 4 – Determine small-scale sugarcane growers' production constraints and perceptions of pests, pest control and push-pull, and asses the feasibility of push-pull for use by small-scale sugarcane growers

In Chapter 4, a mixed methods approach was used to determine whether push-pull was a suitable pest management strategy for small-scale sugarcane growers in the South and Lower South Coast regions. Like Cockburn (2013), this study found that SSGs livelihoods rely on a diverse assemblage of crops, livestock and employment activities. SSG agriculture in the coastal areas serves both a subsistence and a commercial purpose. Although SSGs rely on a number agriculture endeavours, sugarcane was found to play a significant role in the lives of SSGs, and farmers perceived sugarcane as their main source of income. Sugarcane production in these regions provides SSGs with money for food, childhood education and household improvements. As stated by Cockburn (2013), these findings are in consensus with other studies discussing the importance of sugarcane for rural development (Eweg 2005, Armitage et al. 2009, Sibiya and Hurley 2011).

Unlike SSGs in the Midlands North, farmers in the coastal regions acknowledged insect pests as a major production constraint. SSGs knowledge of sugarcane pests is also relatively good, with many respondents correctly identifying and discussing the known pests of sugarcane. This supports the findings that pests are considered a production constraint by SSGs, since farmers know about sugarcane pests and can readily recognise them (Chitere and Omolo 1993, Bottenberg 1995, Arshad et al. 2008). Stem borers were perceived to be the most damaging pest of sugarcane, with some famers singling out *E. saccharina* as the most abundant of the sugarcane pests. As such, IPM and push-pull technology have the potential to reduce infestations and improve small-scale sugarcane outputs and profit margins. Additionally, smallholders generally have complex farming systems, and often employ activities such as intercropping, crop rotation (Altieri et al. 2012, Khan et al. 2014). Low chemical inputs mean that natural enemy abundances are typically conserved on small-scale farms (Altieri et al. 2012). Therefore, coastal SSGs are well positioned to adopt and implement push-pull and other IPM technologies without drastic changes to their farming systems. The small-scale growers also expressed enthusiasm over push-pull, and some farmers made efforts to start growing *M. minutiflora* on their farms. If the efficacy of push-pull is demonstrated to these growers through the use of demonstration plots, and if plants are provided to the growers, it is predicted that many farmers would attempt to adopt push-pull.

Although SSGs demonstrated a high-level of knowledge when it came to sugarcane pests, many farmers also perceived beneficial organisms as production constraints. This demonstrates that farmers unaware of the positive role that natural enemies play in the environment and that there is lack of knowledge of basic ecological processes within the agroecosystem (Abate et al. 2000, van Huis and Meerman 2009). SSGs are also unfamiliar with the different types of pest control mechanisms that can be used to manage pest populations in sugarcane. Therefore, there is a need for extension and advisory services to continue concentrating on pest management practices and to educate SSGs about beneficial organisms, as well as the variety and application of pest and disease control strategies (Armitage et al. 2009, Cockburn 2013, Eweg 2005).

SSGs also identified input costs and weeds as important production constraints. In addition to these constraints, it is evident that SSGs perceive food crop pests to be a greater farming constraint than sugarcane pests. For push-pull to be successful in this region it must be able to address some of the additional issues and constraints faced by coastal SSGs. The push-pull program in East Africa focussed on suppressing stem borer populations in maize, but it also increased farm profits by controlling other pests within the agroecosystem and by proving famers with fodder for their livestock (Fischler 2010, Khan et al. 2014). This multi-focal approach contributed to the success of push-pull in East Africa (Khan et al. 2014).

5.2. Closing synthesis and recommendations for further research

This research has provided valuable information regarding the efficacy of push-pull for the control of *E. saccharina* in the coastal sugarcane growing regions of South Africa. It has also provided researchers with new insights into the mechanisms driving the adoption of PPT and other IPM practices amongst both large and small-scale sugarcane growers. However, to achieve the aim of increasing the implementation of PPT on coastal sugarcane farms, it is imperative that long-term studies and demonstration plots be developed to provide farmers with examples of push-pull in action. Further collaboration is also needed between SASRI researchers, extension staff, LPD&VCC, industry officials mills and farmers to develop incentives for farmers, improve their socio-economic state, increase their education of IPM technologies, and provide them with the materials they need to begin implementing push-pull and other SUSfarms techniques. Collaboration is also needed to tailor PPT to farmers situations, using their own local knowledge and experience, to improve the applicability of push-pull and other holistic farming practices. As mentioned by Cockburn (2013), the movements of *E. saccharina* and its natural enemies between sugarcane habitats and wetland habitats also need to be studied further. This will provide farmers with motivation to conserve their wetland habitats and help to alleviate some of the fears that farmers have about wetlands becoming a source of *E. saccharina* infestation. More research is needed to assess the real impact of *E. saccharina* on small-scale, rural sugarcane farms to determine whether additional pest management services are required to improve the livelihoods of SSGs and so that stakeholders can act accordingly to mitigate any potential crop losses. Although *M. minutiflora* and wetland sedges were deemed effective push-pull plants in this study, it is necessary to investigate alternative push-pull plants for use by farmers who do not have access to these plants or the habitats required to facilitate their growth. Finally, the financial instability of both the large-scale and small-scale sugarcane growers in this study warrants the development of an accurate cost-benefit analysis of push-pull implantation in coastal sugarcane. Farmers need to know whether this technology will be profitable before they begin to employ push-pull on their farms.

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Appendix

A: Chapter 2

Results of Pearson chi-square analyses testing for differences between percentage of stalks damaged between different sites at the push-pull trials on each of the model farms (refer to Figure 2.3):

Pairs of variables compared on each model farm	X^2	p-value
A: Kahlamba Estate push-pull trials		
Treatment (Before) vs. Treatment (After)	21.418	<0.001
Control (Before) vs. Control (After)	32.674	<0.001
Treatment (Before) vs. Control (Before)	79.787	<0.001
Treatment (After) vs. Control (After)	1.473	0.225
Treatment (Before) vs. Control (After)	11.864	<0.001
Control (Before) vs. Treatment (After)	20.625	<0.001
B: Evelyn Park push-pull trials		
Treatment (Before) vs Treatment 2 (Before)	3.030	0.082
Treatment (Before) vs Fastac (Before)	119.171	<0.001
Treatment (Before) vs Control (Before)	27.472	<0.001
Treatment (Before) vs Treatment (After)	69.758	<0.001
Treatment (Before) vs Treatment 2 (After)	55.009	<0.001
Treatment (Before) vs Fastac (After)	127.847	<0.001
Treatment (Before) vs Control (After)	31.641	<0.001
Treatment 2 (Before) vs Fastac (Before)	151.015	<0.001
Treatment 2 (Before) vs Control (Before)	46.673	<0.001
Treatment 2 (Before) vs Treatment (After)	96.527	<0.001
Treatment 2 (Before) vs Ttreatment (After)	79.660	<0.001
Treatment 2 (Before) vs Fastac (After)	160.364	<0.001
Treatment 2 (Before) vs Control (After)	51.857	<0.001
Fastac (Before) vs Control (Before)	37.348	<0.001
Fastac (Before) vs Treatment (After)	8.341	0.004
Fastac (Before) vs Treatment 2 (After)	15.091	<0.001
Fastac (Before) vs Fastac (After)	0.216	0.642
Fastac (Before) vs Control (After)	38.011	<0.001
Control (Before) vs Control (After)	0.161	0.688
Control (Before) vs Treatment (After)	10.923	<0.001
Control (Before) vs Treatment 2 (After)	5.290	0.021
Control (Before) vs Fastac (After)	42.850	<0.001
Treatment (After) vs Treatment 2 (After)	1.030	0.310
Treatment (After) vs Fastac (After)	11.183	<0.001
Treatment (After) vs Control (After)	8.458	0.004
Treatment 2 (After) vs Fastac (After)	18.795	<0.001
Treatemnt 2 (After) vs Control (After)	3.612	0.574
Fastac (After) vs Control (After)	38.011	<0.001
C: Glen Rosa push-pull trials		

Treatment (Before) vs. Treatment (After)	2.028	0.154
Control (Before) vs. Control (After)	9.760	0.002
Treatment (Before) vs. Control (Before)	3.931	0.474
Treatment (After) vs. Control (After)	0.061	0.804
Treatment (Before) vs. Control (After)	1.387	0.239
Control (Before) vs. Treatment (After)	11.294	<0.001
D: Sezela MCP push-pull trials		
Treatment (Before) vs. Treatment (After)	8.408	0.004
Control (Before) vs. Control (After)	2.952	0.086
Treatment (Before) vs. Control (Before)	3.208	0.073
Treatment (After) vs. Control (After)	0.819	0.365
Treatment (Before) vs. Control (After)	12.206	<0.001
Control (Before) vs. Treatment (After)	1.762	0.184
E: Ellingham Estate push-pull trials		
Treatment (Before) vs. Treatment (After)	8.859	0.003
Control (Before) vs. Control (After)	5.329	0.021
Treatment (Before) vs. Control (Before)	7.868	0.005
Treatment (After) vs. Control (After)	12.042	<0.001
Treatment (Before) vs. Control (After)	0.251	0.617
Control (Before) vs. Treatment (After)	32.726	<0.001

Results of Pearson chi-square analyses testing for differences between number of *Eldana saccharina* found per 100 stalks between different sites at the push-pull trials on each of the model farms (refer to Figure 2.4):

Pairs of variables compared on each model farm	**X^2**	**p-value**
A: Kahlamba Estate push-pull trials		
Treatment (Before) vs. Treatment (After)	7.100	0.008
Control (Before) vs. Control (After)	12.090	0.001
Treatment (Before) vs. Control (Before)	29.165	<0.001
Treatment (After) vs. Control (After)	0.387	0.533
Treatment (Before) vs. Control (After)	4.210	0.040
Control (Before) vs. Treatment (After)	8.306	0.004
B: Evelyn Park push-pull trials		
Treatment (Before) vs Treatment 2 (Before)	0.5137	0.474
Treatment (Before) vs Fastac (Before)	49.5181	<0.001
Treatment (Before) vs Control (Before)	10.7143	<0.001
Treatment (Before) vs Treatment (After)	28.8843	<0.001
Treatment (Before) vs Treatment 2 (After)	18.9657	<0.001
Treatment (Before) vs Fastac (After)	70.9311	<0.001
Treatment (Before) vs Control (After)	17.9067	<0.001
Treatment 2 (Before) vs Fastac (Before)	58.8728	<0.001
Treatment 2 (Before) vs Control (Before)	15.7942	<0.001
Treatment 2 (Before) vs Treatment (After)	36.5643	<0.001

Treatment 2 (Before) vs Ttreatment 2 (After)	25.4357	<0.001
Treatment 2 (Before) vs Fastac (After)	81.2891	<0.001
Treatment 2 (Before) vs Control (After)	24.2232	<0.001
Fastac (Before) vs Control (Before)	16.2677	<0.001
Fastac (Before) vs Treatment (After)	3.6772	0.552
Fastac (Before) vs Treatment 2 (After)	8.8417	0.003
Fastac (Before) vs Fastac (After)	3.7366	0.053
Fastac (Before) vs Control (After)	9.5916	0.002
Control (Before) vs Control (After)	0.9817	0.322
Control (Before) vs Treatment (After)	4.8427	0.028
Control (Before) vs Treatment 2 (After)	1.2539	0.263
Control (Before) vs Fastac (After)	31.9187	<0.001
Treatment (After) vs Treatment 2 (After)	1.1905	0.275
Treatment (After) vs Fastac (After)	13.8082	<0.001
Treatment (After) vs Control (After)	1.4879	0.226
Treatment 2 (After) vs Fastac (After)	21.9139	<0.001
Treatemnt 2 (After) vs Control (After)	0.0168	0.897
Fastac (After) vs Control (After)	22.9826	<0.001
C: Glen Rosa push-pull trials		
Treatment (Before) vs. Treatment (After)	1.9877	0.159
Control (Before) vs. Control (After)	3.635	0.057
Treatment (Before) vs. Control (Before)	1.822	0.177
Treatment (After) vs. Control (After)	0.623	0.430
Treatment (Before) vs. Control (After)	0.410	0.522
Control (Before) vs. Treatment (After)	6.564	0.011
D: Sezela MCP push-pull trials		
Treatment (Before) vs. Treatment (After)	18.935	<0.001
Control (Before) vs. Control (After)	0.7771	0.378
Treatment (Before) vs. Control (Before)	6.6847	0.010
Treatment (After) vs. Control (After)	0.853	0.356
Treatment (Before) vs. Control (After)	11.928	<0.001
Control (Before) vs. Treatment (After)	3.2471	0.071
E: Ellingham Estate push-pull trials		
Treatment (Before) vs. Treatment (After)	10.7143	0.001
Control (Before) vs. Control (After)	2.380	0.123
Treatment (Before) vs. Control (Before)	5.561	0.018
Treatment (After) vs. Control (After)	16.456	<0.001
Treatment (Before) vs. Control (After)	2.380	0.123
Control (Before) vs. Treatment (After)	30.2521	<0.001

Results of the multi-factorial ANOVA, and subsequent post-hoc Tukey HSD test, testing for differences in the % internodes damaged between different sites before and after the push-pull trials were conducted on model farms on the North Coast (refer to Figure 2.5.1).

Tukey HSD test: % internodes damaged (A: Kahlamba Estate), MS error = 125.29, df = 796.0

	Site	Treatment	1	2	3	4
1	Treatment site	Before		<0.001	<0.001	<0.001
2	Treatment site	After	<0.001		0.241	0.566
3	Control	Before	<0.001	0.241		0.008
4	Control	After	<0.001	0.566	0.008	

Tukey HSD test: % internodes damaged (B: Evelyn Park), MS error = 96.08, df = 1592.0

	Site	Treatment	1	2	3	4	5	6	7	8
1	Treatment site	Before		<0.001	<0.001	<0.001	0.843	<0.001	<0.001	<0.001
2	Treatment site	After	<0.001		0.014	0.589	<0.001	0.9993	0.387	0.147
3	Control	Before	<0.001	0.0138		0.757	<0.001	0.078	<0.001	<0.001
4	Control	After	<0.001	0.589	0.757		<0.001	0.905	0.002	<0.001
5	Treatment site 2	Before	0.843	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
6	Treatment site 2	After	<0.001	0.9993	0.078	0.905	<0.001		0.121	0.031
7	Fastac	Before	<0.001	0.387	<0.001	0.002	<0.001	0.121		0.9997
8	Fastac	After	<0.001	0.147	<0.001	<0.001	<0.001	0.031	0.9997	

Results of the multi-factorial ANOVA, and subsequent post-hoc Tukey HSD test, testing for differences in the % internodes damaged between different sites before and after the push-pull trials were conducted on model farms on the South Coast (refer to Figure 2.5.2).

Tukey HSD test: % internodes damaged (A: Glen Rosa), df = 398.0

	Site	Treatment	1	2
1	Treatment site	After		0.890
2	Control	After	0.890	

Tukey HSD test: % internodes damaged (B: Sezela MCP), MS error = 121.49, df =796.0

	Site	Treatment	1	2	3	4
1	Treatment site	Before		<0.001	0.215	<0.001
2	Treatment site	After	<0.001		<0.001	0.930
3	Control	Before	0.215	<0.001		0.001
4	Control	After	<0.001	0.930	0.001	

Tukey HSD test: % internodes damaged (C: Ellingham Estate), MS error = 124.09, df =796.0						
	Site	**Treatment**	**1**	**2**	**3**	**4**
1	Treatment site	Before		0.286	<0.001	0.961
2	Treatment site	After	0.286		<0.001	0.106
3	Control	Before	<0.001	<0.001		<0.001
4	Control	**After**	0.961	0.106	<0.001	

B: Chapter 3

Questionnaire used for large-scale growers' survey:

Farm Name: ___________________________ Date: __________________

Farmers Name: ________________________

The following questionnaire has been formulated to gain a better understanding of farmers' production constraints, pest related issues and the management tactics that farmers employ against pest infestations. The questionnaire is also designed to help understand grower perceptions of new pest control techniques. The aim of this research is to determine if these strategies suite the needs of sugarcane farmers, and to improve the dissemination of other new technologies in the future.

PART 1: PREINTRODUCTORY SURVEY

1. Gender: ....
2. Age: ....
3. How long have you been farming sugarcane? ....
4. Do you have tertiary education? ....
5. If yes, where did you study and what course did you study? ....
6. Any additional agricultural training? ....
7. If yes what topic did you train in?...
8. What is your relationship with this farm/land? Owner, Manager, shareholder, owner/manager or other? ....
9. Which other crops or livestock do you farm on your land? ....
   ....

PART 2: GENERAL INSECT PEST MANAGEMENT QUESTIONS

1. What is the biggest problem affecting sugarcane yield on your farm? Please rank the following constraints from 1-7 (1 being the worst and 6 being the least problematic).
   - Soil
   - Weeds
   - Rainfall
   - Insect pests
   - Disease
   - Frost
   - Variety choice

2. Are there any other constraints affecting your farm? Please specify: ....
3. Which pest and or disease problems is the worst on your farm? ....
4. Please rank the following insect pests according to the problems they present to your farm. Rank on a scale of 1-5 (1 being the worst and 5 being the least problematic).
    - Eldana
    - White grub
    - Sesamia
    - Thrips
    - Aphids
5. Are there any other noticeable insect pests? Please specify: ....
6. Have you ever used insecticides on your sugarcane? ....
7. If yes, which insect were you controlling and what insecticides do you use?..............................
   ....
8. What methods do you use to apply insecticide? ....
   ....

PART 3: MANAGEMENT QUESTIONS:

1. Can you identify Eldana larvae? ....
2. Can you identify Eldana moths? ....
3. Can you identify Eldana damage? ....
4. Has Eldana ever been found on your farm? ....
5. Did you know that Eldana numbers increase when the cane is stressed? ....
6. Did you know that Eldana's numbers and range are slowly expanding to include new previously 'safe areas'? ....
7. Please choose a response to this statement: Eldana is currently a threat to sugarcane production in the North and South Coast regions.
    - Strongly agree
    - Agree
    - Neutral
    - Disagree
    - Strongly disagree
8. How worried are you about Eldana possibly affecting your sugarcane yields in the future?
    - Very worried
    - Slightly worried
    - Neutral
    - Not worried
    - It hasn't even crossed my mind
9. How seriously is Eldana impacting the sugarcane production on your farm at the moment? Choose a number 1-5. (1 is extremely serious and 5 is of least concern): ....
10. Why did you choose this option in the question above? ....
    ....

11. What do you do to control Eldana on your farm? Rank the following control measures from 1-5 (1 being the method you use the most and 5 being the method you use the least).
    - Spray
    - Monitoring
    - Hygiene & cutting
    - Habitat management
    - Variety choice
12. Have you heard of Integrated Pest Control as a method for controlling Eldana? ....
13. Have you heard of habitat management or push-pull as a method to controlling Eldana? ....
    ....
14. Have you had any discussions about push-pull, habitat management or IPM with other farmers, millers, researchers or extension officers? Have these discussions been mostly positive, negative, or both? ....
15. Where did you first hear about IPM/ habitat management/ push-pull?
    - General reading
    - Other farmers
    - PnD days
    - SASRI information packs/ pamphlets
    - Other – please specify.
16. Do you know these push-pull plants? Please say yes, no, maybe for each option.
    - Melinus minutiflore/ Molasses grass
    - Bt Maize
    - Sedges
    - Cyperus dives
    - Cyperus papyrus
17. Do you know how Bt Maize works? If yes, please explain: ....
    ....
    ....
18. Do you know where to get Bt Maize? ....
19. Do you think that you would be able to grow Bt Maize on your farm as part of a push-pull project? ....
20. Do you know where to get Molasses grass? ....
21. Do you know where to get sedges/ Cyperus species? ....

PLEASE READ THE FOLLOWING ARTICLE BEFORE ANSWERING THE REMAINING QUESTIONS.

SASRI has always recommended an integrated approach to eldana control, i.e. the simultaneous application of several different control measures. These include, among others, correct choice of variety, good soil and crop management practices, such as careful fertiliser applications, cutting cane at the correct age and good field hygiene. For many years now, SASRI has been exploring habitat manipulation (or the "push-pull" method, as it is more popularly known) as an additional measure for the integrated approach to eldana control.

Push-pull works by managing the behaviour of the female moth so that less eldana eggs are laid in cane and so damage to cane is reduced. 'Push' plants give off volatile chemicals which discourage the moth from laying eggs in the sugarcane (they also attract parasitoids), and eggs are laid in 'pull' plants, which are more attractive to the moth, instead. When eldana eggs are laid in indigenous 'pull' plants in wetlands, they are more accessible to their natural enemies and the population can be controlled naturally. Bt maize is also used as a 'pull' plant. It is referred to as a 'dead-end' trap crop as it is toxic to moth caterpillars and kills them within the first two days of feeding. You do not need to sacrifice any land used for sugarcane to plant push-pull: push and pull plants are planted in contours, waterways, watercourses and wetlands.

In one trial conducted at SASRI, push-pull (when used in conjunction with the other measures listed above) reduced damage from eldana by over 50%. This work is now being explored further as part of an MSc project, jointly funded by North-West University and National Research Foundation. The project involves a team of researchers and Extension Specialists working closely with the Pest & Disease office in the Wartburg area to implement push-pull in the Midlands North area. They are working with both small-scale and commercial growers and are trying to encourage farmers to plant push-pull plants on their farms to reduce the risk of infestation by eldana.

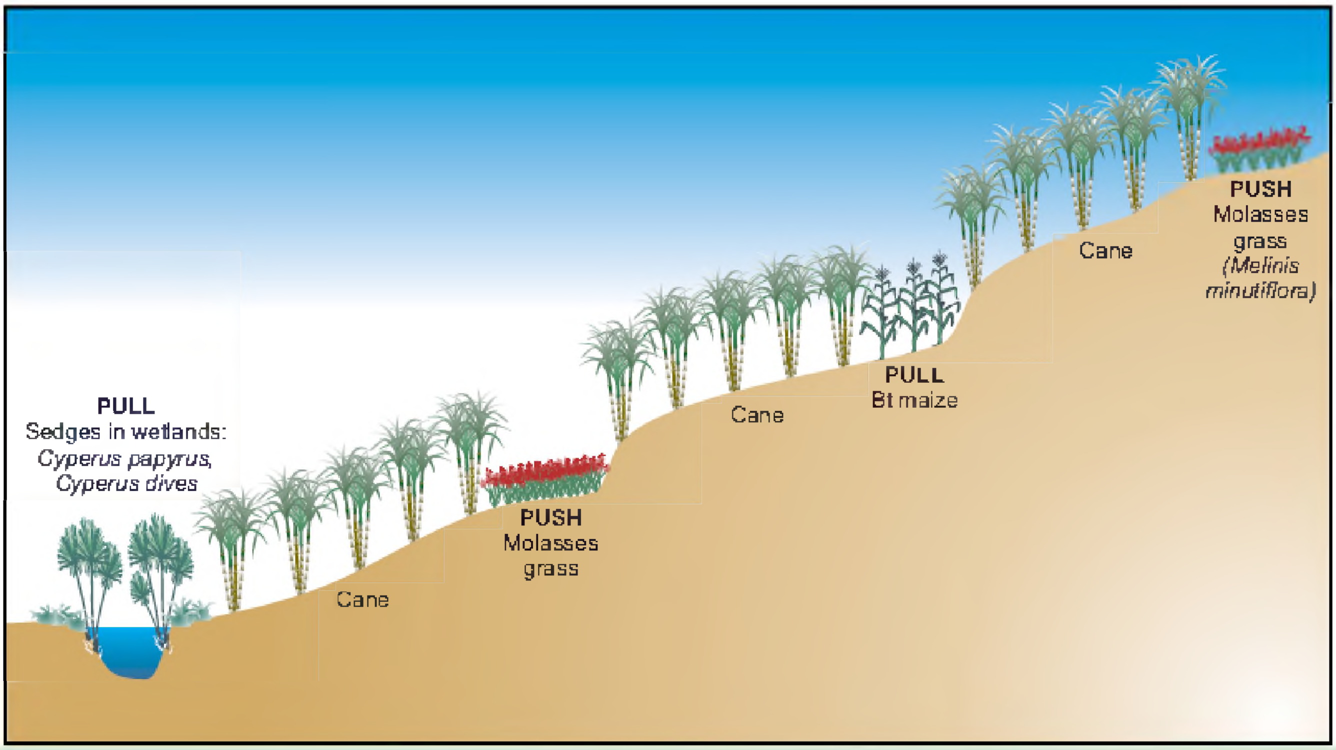
For the control of eldana in sugarcane, Molasses grass (*Melinis minutiflora*) is being used as a "push plant" to repel female moths from the cane. The Molasses grass is planted along the contours approximately 20 rows apart, and at least 20 rows away from any wetland or watercourse. Generally contours, drainage lines and/or irrigation paths are around this distance apart, and form good places to plant the push and pull plants.

The "pull plants" used are Bt maize and various species of sedges. Bt maize should be planted along every 4th contour bank / terrace bank or along the outer borders of the cane field. Sedges are planted in wetlands bordering the cane fields. To mitigate the risk of mosaic, maize should be planted at the correct time of year (January) and only insecticide-treated seed should be used.

Sedges used as pull plants include *Cyperus dives* and *Cyperus papyrus*. For push-pull to be effective it is important that farmers work actively to keep their wetlands healthy and to promote the growth of natural 'pull' plants for eldana such as these sedges.

The push and pull plants also have additional uses over and above controlling eldana. Molasses grass can be cut and used as a good cattle fodder. Bt maize, which is resistant to damage by stemborers such as eldana, can be used for human consumption or as a cattle feed. The sedges, if managed well, can be used for weaving and basketry and also have medicinal properties.

By Jessica Cockburn (MSc student) and Des Conlong (Senior Entomologist)



22. Do you read the SASRI pamphlets/ packs that are sent to you?
    - Yes always
    - Yes mostly
    - Sometimes
    - No not that much
    - No never
23. Do you think push-pull/ habitat management as part of an IPM approach is a good method for controlling Eldana?
    - Yes
    - No
    - Maybe
    - I don't know habitat management
    - Other – specify
24. Do you know how to implement push-pull/ habitat management on your farm? ....
25. Do you think you understand the practical and cost implications of habitat management? .....

PART 4: QUESTIONS ABOUT EXTENSION WORK

1. Is the information you receive about pest management from SASRI / the local PnD office useful to you? ....
2. Are you interested in receiving more information on pest management than you currently are? ....
3. Would you like to learn more about push-pull/ habitat management for controlling Eldana? ....
4. How would you like to learn more about push-pull and other methods for controlling Eldana? Rank from 1-5 (1 the one you'd be most interested in, 5 being the one you'd be least interested in).
    - Farmer info days
    - Visiting model farms which show the methods
    - Pamphlets of info by email
    - Interactive workshops
    - Personal contact with PnD/ SASRI extension officer
5. How often would you like to receive info/ new updates regarding pest management from SASRI/ the PnD offices?
    - Once a year
    - 2- 3 times a year
    - Once a month
    - Other
    - Workshops
6. Are you willing to be involved in future research toward introducing push-pull for control of Eldana in this area? ....
....
....

7. How would you suggest we go about introducing a new method like push-pull for control of Eldana in this area?
………
………
………
………
………
………………………………………………………………………………………

8. What do you see as the biggest barrier to us introducing a new method like push-pull for Eldana amongst farmers?
………
………
………
………
………
………
………………………………………………………………………………………………………

9. Do you think a holistic IPM technology such as push-pull will work on your farm and would you employ it?
………
………
………
………
………
………
………………………………………………………………………………………………………

THANK YOU FOR YOUR FEEDBACK!

Results of the Kruskal-Wallis one-way ANOVA testing for differences between ranks allocated by LSGs to different sugarcane production constraints that they experience on their farms (refer to Figure 3.1).

Kruskall-Wallis rank test: LSGs Production contraints, multiple comparisons of p-values, H = 280,014								
	Production Constraint	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Rain		<0.001	<0.001	0.218	<0.001	<0.001	<0.001
2	Soil	<0.001		0.195	0.426	<0.001	<0.001	0.004
3	Weeds	<0.001	0.195		<0.001	1.0	<0.001	1.0
4	Insect pests	0.218	0.426	<0.001		<0.001	<0.001	<0.001
5	Disease	<0.001	<0.001	1.0	<0.001		<0.001	1.0
6	Frost	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001
7	Variety choice	<0.001	0.004	1.0	<0.001	1.0	<0.001	

Results of the Kruskal-Wallis one-way ANOVA testing for differences between ranks allocated by LSGs to different insect pests that they experience on their farms (refer to Figure 3.3).

Kruskall-Wallis rank test: LSGs worst insect pests, multiple comparisons of p-values, H = 253,631						
	Insect pests	**1**	**2**	**3**	**4**	**5**
1	Eldana		<0.001	<0.001	<0.001	<0.001
2	White grub	<0.001		0.003	<0.001	<0.001
3	Sesamia	<0.001	0.003		<0.001	0.003
4	Thrips	<0.001	<0.001	<0.001		0.117
5	Aphids	<0.001	<0.001	0.003	0.117	

Results of the Kruskal-Wallis one-way ANOVA testing for differences between ranks allocated by LSGs to different control tactics that they use on their farms to manage *Eldana saccharina* populations and damage (refer to Figure 3.5).

Kruskall-Wallis rank test: LSGs pest control tactics for *Eldana saccharina*, multiple comparisons of p-values, H = 141,626						
	Control tactics	**1**	**2**	**3**	**4**	**5**
1	Insecticide		0.116	<0.001	<0.001	0.011
2	Monitoring	0.116		0.640	<0.001	1.0
3	Cultural controls	<0.001	0.640		<0.001	1.0
4	Push-pull	<0.001	<0.001	<0.001		0.011
5	Variety choice	0.011	1.0	1.0	0.011	

Results of the Kruskal-Wallis one-way ANOVA testing for differences between ranks allocated by LSGs to different methods of extension that can be used to aid farmers in learning about new pest management technologies (refer to Figure 3.7).

Kruskall-Wallis rank test: LSGs preferred extension methods, multiple comparisons of p-values, H = 42.060						
	Communication method	**1**	**2**	**3**	**4**	**5**
1	Workshop/info days		1.0	0.819	<0.001	1.0
2	Model farms	1.0		0.083	<0.001	1.0
3	Pamphlet/emails	0.819	0.083		0.214	0.011
4	Interactive study groups	<0.001	<0.001	0.214		<0.001
5	Personal extension visits	0.1	1.0	0.011	<0.001	

B: Chapter 4

Results of the multi-factorial ANOVA, and subsequent post-hoc Tukey HSD test, testing for differences between the number of matchsticks allocated by SSGs to quantify the inputs that each farmer dedicates to different sugarcane and non-sugarcane agricultural enterprises (refer to Figure 4.9).

Tukey HSD test: mean no. matchsticks allocated by SSGs (SSG agricultural inputs), MS error = 51.262, df =204.0								
	Agricultural enterprise	**SSG inputs**	**1**	**2**	**3**	**4**	**5**	**6**
1	Cane	Expenses		0.619	0.173	0.994	<0.001	<0.001
2	Cane	Work-effort	0.619		0.001	0.277	<0.001	<0.001
3	Non-cane	Expenses	0.173	0.001		0.464	<0.001	<0.001
4	Non-cane	Work-effort	0.994	0.277	0.464		<0.001	<0.001
5	Mean non-cane	Expenses	<0.001	<0.001	<0.001	<0.001		0.998
6	Mean non-cane	Work-effort	<0.001	<0.001	<0.001	<0.001	0.998	

Results of the multi-factorial ANOVA, and subsequent post-hoc Tukey HSD test, testing for differences between the number of matchsticks allocated by SSGs to quantify the outputs that each farmer gains from different sugarcane and non-sugarcane agricultural enterprises (refer to Figure 4.10).

Tukey HSD test: mean no. matchsticks allocated by SSGs (SSG agricultural inputs), MS error = 51.262, df =204.0								
	Agricultural enterprise	**SSG outputs**	**1**	**2**	**3**	**4**	**5**	**6**
1	Cane	Income		0.001	0.899	0.055	<0.001	<0.001
2	Cane	Food	0.001		0.001	0.001	0.999	0.794
3	Non-cane	Income	0.899	0.001		0.002	<0.001	<0.001
4	Non-cane	Food	0.055	<0.001	0.002		<0.001	<0.001
5	Mean non-cane	Income	<0.001	<0.001	<0.001	<0.001		0.929
6	Mean non-cane	Food	<0.001	0.794	<0.001	<0.001	0.929	