Chapter 6

Wetlands as a farm resource: Monitoring stem borers and assessing wetland health on sugarcane farms

6.1 Introduction

Push-pull is a stimulo-deterrent diversionary approach to managing *Eldana saccharina* Walker (Lepidoptera: Pyralidae) in sugarcane, whereby an indigenous repellent grass, *Melinis minutiflora* P. Beauv (Cyperales: Poaceae), is planted between sugarcane fields, while attractant plants provide alternate oviposition sites (Conlong and Rutherford, 2009; Rutherford and Conlong, 2010). The attractant plants used in this system are Bt maize, which has been shown to be more attractive to egg-laying moths than sugarcane when maize plants are old and carry large amounts of dry leaf matter (Keeping *et al.*, 2007), and two species of indigenous sedges of the genus *Cyperus*. *Cyperus papyrus* L. (Cyperales: Cyperaceae) and *Cyperus dives* Delile (Cyperales: Poaceae) are the indigenous host plants of *E. saccharina* which grow in wetlands throughout the coastal areas of KwaZulu-Natal. A diagram of the push-pull system which is prompted within an IPM framework by the South African Sugarcane Research Institute (SASRI) is provided in Chapter 4 (Figure 4.1).

In conservation biological control agroecosystems are manipulated to protect and enhance locally occurring natural enemies, thereby reducing the effect of pests on the crop (Ehler, 1998), and push-pull is an example of a conservation biological control strategy. Agroecological approaches such as conservation biological control are needed to reduce reliance on agrochemical inputs and to improve agricultural sustainability (Altieri and Nicholls, 2004). This is particularly pertinent since worldwide loss of biodiversity has been attributed largely to agricultural intensification (MA, 2003; Altieri and Nicholls, 2004), and increased demand for sugarcane as a biofuel could result in increased habitat destruction through clearing for sugarcane cultivation (Goebel and Sallam, 2011). Agricultural monocultures are highly simplified landscapes which are prone to higher pest populations and resultant crop damage (Altieri and Nicholls, 2004; Bianchi *et al.*, 2006) as beneficial functions of biodiversity are disrupted (Tscharntke *et al.*, 2012). By implementing conservation biological control, for example push-pull for control of *E. saccharina* in sugarcane, agroecosystems are diversified resulting in increased stability and resilience of agroecosystems, and increased conservation of biodiversity in agricultural ecosystems (Altieri and Nicholls, 2004; Gurr *et al.*, 2012). This has also been an important principle of the successful push-pull programme in Kenya, described in Chapter 1 (Khan *et al.*, 1997b; Khan *et al.*, 2011).

It has been hypothesized that *E. saccharina* became a pest with the rapid expansion of sugarcane cultivation during the early 20th century (Osborn, 1964). During this period the expansion of sugarcane cultivation resulted in large-scale destruction of wetland areas (Kotze *et al.*, 1995) which reduced available habitat for *E. saccharina*, forcing the species to adapt to a new host plant (Atkinson, 1980). It is not uncommon for stem borers to increase their host range and many polyphagous African stem borers have switched from wild, indigenous hosts to crop plants and increased their geographical range as crop ranges expanded (Polaszek and Khan, 1998). Stem borers are known to shift between cultivated crop species, for example Assefa *et al.* (2010) recorded *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and *Chilo partellus* Swinhoe (Lepidoptera: Crambidae), both well-known maize stem borers, on sugarcane in Ethiopia. Both of these are important pests of maize in South Africa (Kfir *et al.*, 2002), and thus pose a potential bio-security threat to sugarcane if they undergo a host switch. Knowledge on stem borer species in indigenous host plants in southern Africa is poor, as a recent study of stem borers in wild host plants carried out in South Africa and Mozambique emphasized (Moolman, 2011; Moolman *et al.*, 2012). Thus surveys of stem borers in wild host plants within agricultural ecosystems are important (Polaszek and Khan, 1998).

Eldana saccharina reaches much higher densities and causes greater damage to plant tissues in sugarcane than it does in its indigenous host plants (Conlong, 1990). This is thought to be due to higher nutritional value in surgarcane than in indigenous host plants (Conlong, 1990) and release from natural enemies (Conlong, 1990; Conlong, 1994b; Conlong, 1997a). A diverse range of natural enemies attack multiple life-stages of *E. saccharina* in its indigenous host plants (Conlong, 1990; Conlong, 1994b, 2000), but these natural enemies have not 'followed' *E. saccharina* into the sugarcane crop environment. For this reason, wetlands provide not only a habitat for *E. saccharina* in its indigenous host plants, but also provide a refuge for the natural enemies of this pest and are an important resource for the sustainable management of this pest (Conlong and Kasl, 2000). The importance of wild host plants in providing a refuge for natural enemies of stem borers is widely recognised (Le Rü *et al.*, 2006b; Mailafiya, 2011; Moolman *et al.*, 2012), and a thorough understanding of the dynamic relationships between stem borer populations in wild hosts and those on cultivated crops is crucial for successful development of IPM (Khan *et al.*, 1997b; Polaszek and Khan, 1998).

Wetlands are highly productive and diverse ecosystems which provide multiple ecosystem services, particularly in agricultural environments (Blackwell and Pilgrim, 2011). Ecosystem services are the benefits which people obtain from ecosystems (MA, 2003), and wetlands provide ecosystem services through both hydrological and ecological mechanisms (Blackwell and Pilgrim, 2011). Ecosystem services can be classified according to the functions they perform, i.e. regulation functions, habitat functions, production functions and information functions (de Groot *et al.*, 2002). Regulation of pest populations is recognised as one of the regulatory functions of ecosystem services in agroecosystems (de Groot *et al.*, 2002), and habitat management seeks to maximise the efficacy of this function (Fiedler *et al.*, 2008).

In South Africa, the ecosystem services which wetlands provide are well recognised, although regulation of pest populations is not explicitly mentioned (Kotze *et al.*, 2007). Since wetlands play a key role in regulation of water quality and hydrological processes in landscapes, sugarcane farmers in South Africa are encouraged to manage and conserve the wetlands through the implementation of SUSFARMS (Maher, 2007). SUSFARMS is a farm management system which promotes and guides sustainable farming practices based on economic, social and environmental sustainability (Maher, 2007). The conservation and good management of wetlands through SUSFARMS is based primarily on the water quality and hydrological regulation benefits of wetlands. The pest regulatory functions of wetlands on sugarcane farms are not recognised in SUSFARMS and farmers lack guidelines on how to maximise these pest regulatory ecosystem services. Furthermore, the study on adoption of push-pull using exploratory network analysis in Chapter 4 (Figure 4.3) emphasized the need for farmers to increase their knowledge and understanding of wetland management for effective implementation of push-pull.

Therefore this study has three aims:

- monitoring stem borer and parasitoid populations in wild host plants in wetlands to gain a better understanding of their species composition, interactions and ecology
- assessment of wetlands with a view to providing guidelines for improved management for both hydrological and pest management ecosystem services
- demonstrating the importance of wetlands as part of the agroecosystem on sugarcane farms.

The specific objectives are described in Table 6.1.

Table 6.1 Aims and specific objectives of Chapter 6.

Aim	Specific objectives
Stem borer ecology:	• identify species and host plant associations • identify parasitoid species and determine the rate of parasitism • monitor stem borer incidence and damage in indigenous host plants over one year
Wetland assessments:	• assess wetland health • assess the suitability of wetlands as habitat for stem borers, especially *E. saccharina* • provide recommendations to farmers on how best to manage wetlands for stem borer habitat management and hydrological functioning • develop a tool to aid farmers in management of wetlands for both stem borer management and hydrological functioning
Value of wetlands in sugarcane agroecosystems:	• show the relationships between host plants/stem borer/parasitoid populations in sugarcane and wetlands • synthesize data from this study in the context of relevant literature to demonstrate the value of wetlands

6.2 Materials and methods

6.2.1 Study sites

Where possible, the model farms which were used for push-pull field trials (Chapter 5) were also used to study stem borer ecology and conduct wetland assessments. These farms were all situated in the Midlands North sugarcane growing region in KwaZulu-Natal (Figure 6.1). Stem borer surveys were conducted on Wanderer's Rest, Waterfall and Tweefontein and Bonnieblink. Bonnieblink farm, the neighbouring farm to Cloudhill, was chosen to study stem borers instead of Cloudhill, as there was insufficient natural wetland habitat for stem borers on Cloudhill for repeated, destructive sampling. Wetland assessments were done on Waterfall, Tweefontein and Cloudhill. The wetlands on Wanderer's Rest were riparian areas, i.e. strictly speaking not wetlands, and thus unsuitable for assessment using wetland tools such as WET-Health (Macfarlane *et al.*, 2007). Table 6.2 describes the five farms on which wetland surveys and/or assessments were conducted, including climatic and geographic data for each site.

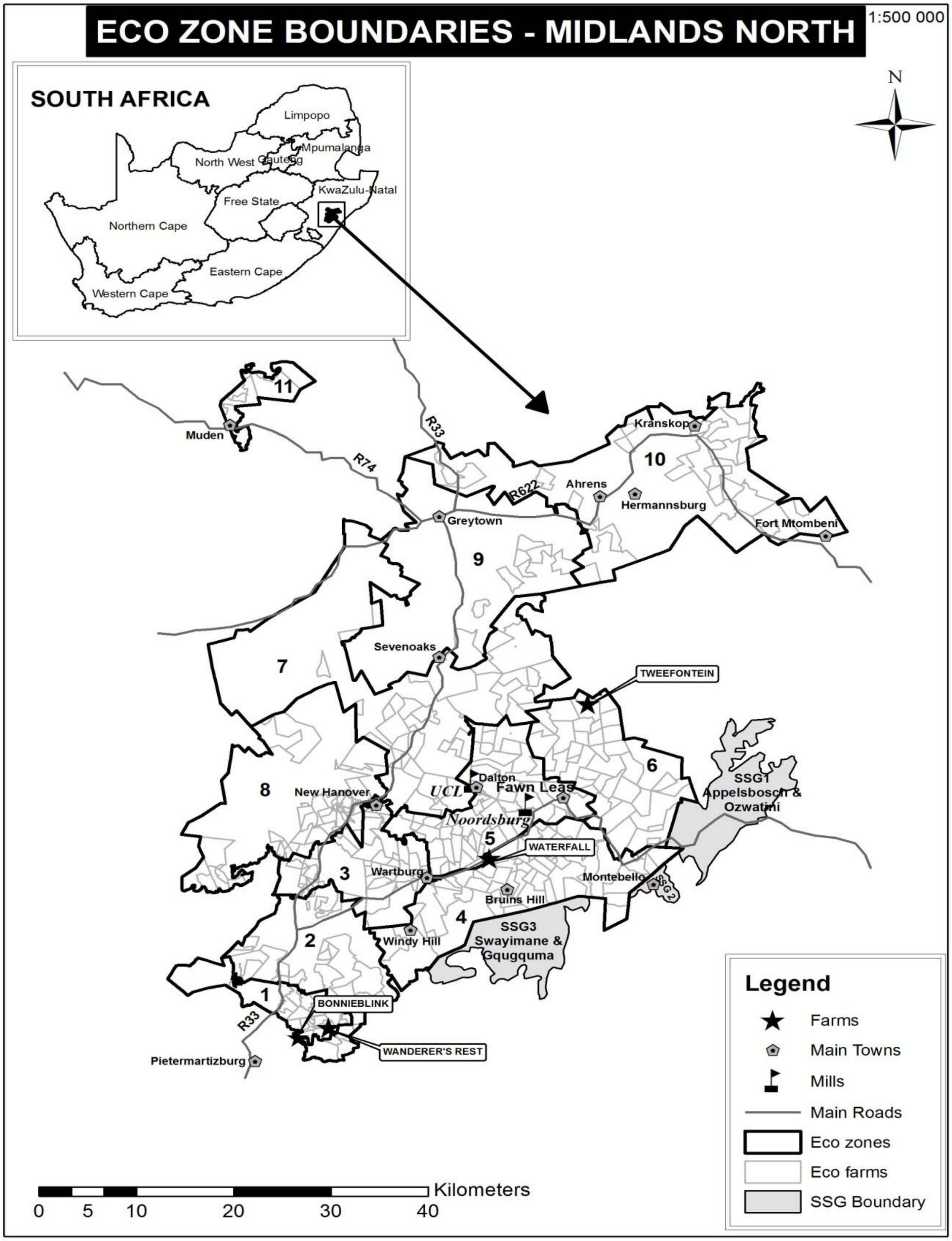

Figure 6.1. Map of the Midlands North sugarcane growing region showing farms used for stem borer surveys and wetland assessments.

Table 6.2 GPS co-ordinates, average climatic conditions and altitude for wetland sites used in this study.

Farm	GPS co-ordinates	Annual rainfall[a,b] (mm)	Min-max (mean) temperature[a,b] (°C)	Altitude (m a.s.l.[c])
Bonnieblink & Cloudhill	29°35'50.77"S 30°26'28.91"E	806	6.9 – 28.1 (19.0)	606
Wanderer's Rest	29°35'12.45"S 30°28'28.41"E	806	6.9 – 28.1 (19.0)	639
Tweefontein	29°15'20.41"S 30°44'47.71"E	795	5.6 – 25.5 (17.1)	908
Waterfall	29°24'38.53"S 30°39'46.03"E	746	7.4 – 26.9 (17.6)	983

[a]climate data from *SASRI WeatherWeb:* (http://portal.sasa.org.za/weatherweb/weatherweb.ww_menus.menu_frame?menuid=1)
[b]rain fall and temperature data calculated over 12 months from September 2011 to August 2012
[c]m a.s.l. = meters above sea level

For stem borer surveys, suitable host plant communities of species belonging to the Poaceae, Typhaceae and Cyperaceae were identified in each wetland on the respective farms, as these are known to be the host plant families most widely used by stem borers in sub-Saharan Africa (Le Rü *et al.*, 2006a; Le Rü *et al.*, 2006b). Only well-established host plant communities were used for the sampling, since sampling was destructive and damage to small or sensitive populations of host plants had to be avoided.

6.2.2 Stem borer ecology in wetlands

Surveys for stem borers were conducted from September 2011 until July 2012. Repeated surveys were carried out at 6-weekly intervals at the same sites, surveying the same host plant patches. A total of eight surveys were completed during this time. The wild host plants surveyed on each farm are listed in Table 6.3. Each farm had a slightly different composition of host plant species, however *C. latifolius* and *T. capensis* were sampled on all four farms.

Although it is known that stem borer abundance in indigenous host plants is very low and that random samples might result in very low incidence of stem borers being recorded (Gounou and Schulthess, 2004), we nevertheless utilised random sampling as it was the most reliable way of ensuring that consistent samples were collected over the nine surveys, even if different people

Table 6.3. Host plant species and wetland plant species type surveyed for stem borers on the designated farms used for the study.

Host Plants	Farm				Wetland plant type[a]
	Bonnieblink	Wanderer's Rest	Tweefontein	Waterfall	
Cyperaceae					
Cyperus latifolius Poir	X	X	X	X	ow
Cyperus dives Delile	X				ow
Cyperus solidus Kunth	X				ow
Cyperus fastigiatus Rottb.			X		ow
Typhaceae					
Typha capensis[b] (Rohrb.) N.E.Br	X	X	X	X	ow
Poaceae					
Phragmites australis (Cav.) Steud.			X	X	ow
Miscanthus capensis (Nees) Anderson		X	X		fw

[a]wetland plant species type can be classified as ow = obligate wetland species, or fw = facultative wetland species (DWAF, 2005; van Ginkel *et al.*, 2011)
[b]*Typha latifolia* has been re-classified as *T. capensis* according to Germishuizen & Meyer (2003), and thus *T. capensis* will be used from now on in this chapter.

were involved in the collection of samples. The sampling unit used in this study was a plantlet, i.e. a single tiller of a plant including roots, rhizomes, a single stem, leaves and a single flower or umbel (if present) (Figure 6.2). For the rest of the chapter, this sampling unit will be referred to as a 'stem'. The number of stems sampled per host plant species was decided based on the size of the host plant population, and this sample number was maintained throughout the survey. Either 25, 50 or 100 stems were sampled per host plant at each site. At each site, a transect of 20 to 30m was selected from the outer edge of the wetland inwards, and random plants were dug out, with roots and rhizomes, and flowers if present, every 2-3 steps along the transect. The specific sites for sampling within each host plant population were chosen based on accessibility throughout both the wet (summer) and dry (winter) seasons.

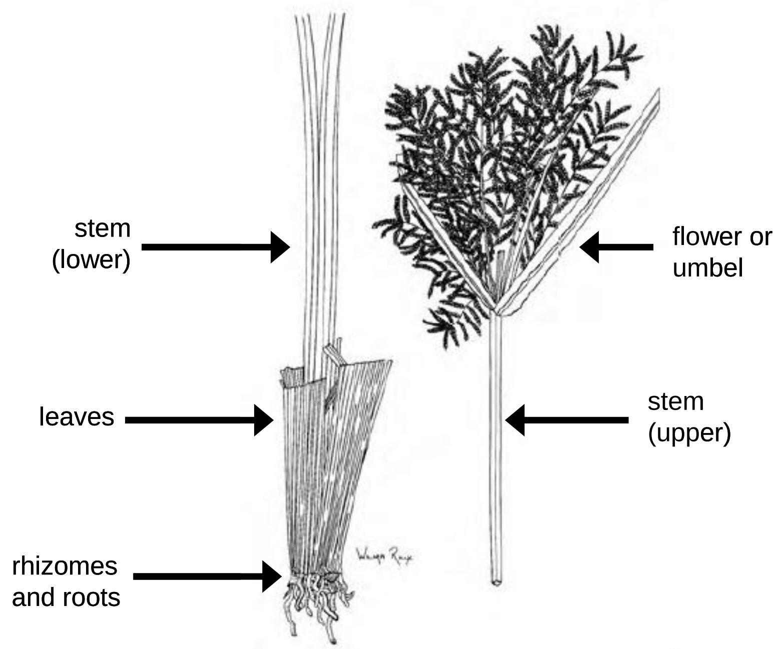

Figure 6.2. Generalised illustration of the different parts of a plant inspected for stem borer damage and infestation during wetland surveys. All parts of the plant as illustrated here were carefully checked for evidence of stem borers. The plant shown here is *Cyperus latifolius* (adapted from DWAF, 2005).

The plants were dissected in the field by splitting them longitudinally with a knife, taking care not to damage any stem borers inside the plants. The stem, flower, rhizome and roots and all leaves, including dry leaves, were carefully inspected for stem borer damage, which is typified by dead hearts (i.e. dead leaves at the apical growth point), scarified leaves, frass, stem feeding damage and exit holes (Le Rü *et al.*, 2006b). To determine the percentage damage and infestation, the presence or absence of stem borer damage and/or live stem borers was scored for each stem (i.e. presence = 1, absence = 0), and a percentage damage/stem borer infestation calculated for each host plant species per site. Any stem borer larvae or pupae found were collected and placed in a labeled 30 ml plastic vial, with a gauze lid, containing 8ml artificial rearing diet (Graham and Conlong, 1988). *Eldana saccharina* larvae were reared on an artificial diet developed specifically for this species, and all other stem borer species were reared on artificial diet developed for *B. fusca*, which had a maize leaf base (Onyango and Ochieng-Odero, 1994). The larvae developed in the SASRI Insect Rearing Unit screening room, at 28°C, 75% relative humidity until adult emergence and/or to determine whether parasitoids had infested the collected larvae or pupae. Larvae were not identified in field but were reared until adults emerged. These were sent for further identification.

This meant that any larvae or pupae which did not reach adulthood due to mortality in the laboratory were not identified. Mortality in the laboratory was due to a number of factors including unsuitable diet and infestations of diet with mites and fungi.

Moths from the Noctuidae family were sent for identification to Dr. B.P. Le Rü at ICIPE, Nairobi, Kenya, where voucher specimens were deposited in the ICIPE Museum, Nairobi. Moths from all other families, together with dipteran parasitoids, were sent for identification to Mrs. V. Uys at the Agricultural Research Council, Plant Protection Research Institute (ARC-PPRI), Biosystematics Division in Pretoria, South Africa and voucher specimens were deposited at the South African National Collection of Insects (SANC), Pretoria. Dr. G.L. Prinsloo identified the hymenopteran parasitoids, which were also deposited at the SANC. Accession numbers of non-noctuid moths and hymenopteran parasitoids are provided in Appendix 3. Where necessary, host plants were identified by Mr. M. Ngwenya of the KwaZulu-Natal Herbarium, Durban, South Africa and voucher specimens were deposited there (*Cyperus solidus* Kunth: NH 135971).

Statistical analysis were done to determine if there were significant differences between stem borer damage and infestation levels of different wild host plants due to survey date and farm. The data was tested for normality and since it was found not to be normal, the Kruskal-Wallis test was used (non-parametric equivalent of one-way ANOVA) (Dytham, 2003) to test for main effects and for interaction effects between survey date, farm an host plant. When a statistically significant effect was found, multiple comparisons of mean ranks were used to elucidate where the effects were, for example, if ‘farm’ was found to have a significant effect, the mean ranks were compared to show which farms had higher or lower damage or infestation levels.

6.2.3 Wetland assessments

Assessments of wetland health were conducted using the WET-Health assessment tool (Macfarlane *et al.*, 2007; Kotze *et al.*, 2012), in consultation with Mr. Vaughan Koopman, wetland ecologist from the Mondi Wetlands Project of the Wildlife and Environment Society of South Africa (http://www.wetland.org.za). WET-Health can be used to assess wetland health by dividing wetlands in hydrogeomorphic units which are examined for three different components of ecosystem health: vegetation, hydrology and geomorphology. These are each examined to determine the extent of anthropomorphic stress factors, such as damming, artificial drainage or infestations of invasive alien plants (IAPs) (Macfarlane *et al.*, 2007), on the wetland ecosystem (Kotze *et al.*, 2012). By mapping the extent of changes to these three ecological components in a wetland as a result of human interference, and comparing these to the ideal natural state of the ecosystem, recommendations can we made to landowners on how best to rehabilitate the wetland to an acceptable condition (Macfarlane *et al.*, 2007).

For purposes of this study, the wetlands were assessed based on hydrological and vegetation indicators only, and not geomorphic indicators, as it was decided that analyzing the geomorphic indicators would take far longer and have little effect on the outcomes of the assessment (Koopman, pers. comm., 2012). A WET-Health Level 1 assessment was carried out. Details of the assessment protocol can be found in Macfarlane *et al.* (2007). The basic steps in assessment are as follows:
Step 1: Divide wetland into hydrogeomorphic units (HGM) units
Step 2: Assess hydrological health and derive a score (0-10: 0-no impact, 10=critical impact)
Step 3: Assess vegetation health of the wetland and derive a score (0-10: 0-no impact, 10=critical impact)
Step 4: Represent the health scores for the overall wetland and designate a 'present ecological state' (PES) category (A-F: A=unmodified/natural, F=critical modifications, see Table 5.26 in Macfarlane *et al*., 2007). An overall health score out of ten can then be calculated (0=pristine, 10=critically impacted). However, Macfarlane *et al.* (2007) caution against this as it may obscure the relative importance of hydrological and vegetation factors contributing to overall wetland health.

To supplement WET-Health assessments, wetlands were further assessed for their suitability as habitat for stem borers, in particular *E. saccharina.* Although no WET-Health assessments were conducted at Wanderer's Rest or Bonnieblink, both farms were also assessed for their suitability as *E. saccharina* habitat, to provide feedback to farmers. This was done by field observations in which obligate wetland plants were used as indicators of soil wetness in a wetland (DWAF, 2005; Clément and Proctor, 2009). *Cyperus dives* and *C. papyrus*, the favoured wild host plants of *E. saccharina,* are both classified as obligate wetland plants found in permanent wetness zones (van Ginkel *et al.*, 2011). Based on field observations, the extent of suitably wet areas for establishment of *C. dives* and *C. papyrus* was mapped and measured using Google Earth (Google Inc., 2011) and GEPath software (Sgrillo, 2011).

By combining the WET-Health assessment and the assessment of wetlands for suitability of *E. saccharina* host plants, recommendations were made to farmers on how best to rehabilitate their wetlands for optimal functioning (hydrologically and ecologically) and to maximize the benefits which wetlands can have for pest management by providing sufficient habitat for *E. saccharina* and its natural enemies. These case studies facilitated the development of a tool for use by farmers to assess and manage wetlands.

6.2.4 Value of wetlands in sugarcane agroecosystems

To demonstrate the value of wetlands in the sugarcane agroecosystem, the pest regulatory ecosystem services they provide were illustrated by synthesizing data from push-pull field trials in Chapter 5 and the data on wetland stem borer ecology (This Chapter). Furthermore, a brief review of literature on stem borers in wild host plants, ecosystem services provided by wetlands and the importance of natural vegetation for stability of agroecosystems was conducted. This was used together with the data to provide context for the discussion.

6.3 Results

6.3.1 Stem borer ecology in wetlands

6.3.1.1 Stem borer species composition and host plant associations

A total of 11983 stems of wetland host plants were surveyed over the 11-month period. Of these stems, 1105 were found to have stem borer damage (9.2%) and 268 stem borer specimens were collected (2.2%). Of these, 154 (57%) died during laboratory rearing and were not identified, 60 were identified as Noctuidae (20%), 47 were identified as *E. saccharina* (18%) and 7 (3%) were non-noctuid stem borers awaiting identification at the ARC-PPRI Biosystematics Division in Pretoria. Noctuidae therefore represent 53% of the stem borers collected and successfully reared to adulthood, *E. saccharina* 41%, and the remaining non-noctuid moths awaiting identification 6%. The abundance and diversity of the stem borers and their host plant associations are shown in Table 6.4. The highest number of stem borer larvae (47), was collected from *C. dives*, and these were almost all *E. saccharina* (Table 6.4). *Typha capensis* yielded the next highest number of stem borers (31). The dominant species in this host plant was the undescribed species *Sesamia* nov. sp. 12 (Table 6.4). *Sesamia* nov. sp. 12 was often found showing gregarious behaviour, with up to 19 individuals infesting a single stem. *Cyperus latifolius* was infested primarily by *Sc. mesophaea* (Table 6.4). *Typha capensis* and *C. latifolius* hosted the highest diversity of stem borer species (4 species each) (Table 6.4). The host plant species in the Poaceae, *P. australis* and *M. capensis,* yielded the lowest number of stem borer species, with only 2 species found in *P. australis* (*Pirateolea piscator* and *Sesamia incerta*) and one in *M. capensis* (*Conicofrontia sesamoides)* (Table 6.4). Waterfall farm had the highest diversity of stem borer species (6 species) and Wanderer's Rest the lowest (none) (Table 6.4).

Table 6.4. Number of stem borer species identified per host plant in wetland surveys on the farms surveyed used in this study[a].

Stem borer family and species	Host plant species					
	Cyperus dives	*Cyperus latifolius*	*Typha capensis*	*Phragmites australis*	*Miscanthus capensis*	Total
Noctuidae						
Conicofrontia sesamoides Hampson	**0**	**0**	**0**	**0**	**1** $_{TF}$	*1*
Pirateolea piscator Fletcher comb. n.	**2** $_{BB}$	**1** $_{BB}$	**0**	**1** $_{TF}$	**0**	*4*
Sciomesa mesophaea Aurivillius	**0**	**15** $_{BB,TF,WF}$	**5** $_{WF}$	**0**	**0**	*20*
Sesamia incerta Walker	**0**	**0**	**0**	**1** $_{WF}$	**0**	*1*
Sesamia nov. sp. 16	**0**	**0**	**1** $_{WF}$	**0**	**0**	*1*
Sesamia nov. sp. 12	**0**	**0**	**29** $_{WF}$	**0**	**0**	*29*
Speia vuteria Stoll	**0**	**0**	**4** $_{WF}$	**0**	**0**	*4*
Pyralidae						
Eldana saccharina Walker	**45** $_{BB}$	**2** $_{BB}$	**0**	**0**	**0**	*47*
Crambidae						
Shoenobiinae sp.	**0**	**1** $_{WF}$	**0**	**0**	**0**	*1*
Total stem borer species per host plant	*47*	*19*	*39*	*2*	*1*	*108*

[a]Letters in subscript indicate farm names: BB: Bonnieblink, WR: Wanderer's Rest, TF: Tweefontein, WF: Waterfall.

Surveys for stem borers in wetland host plants yielded three dominant stem borer species which seemed to show distinct preferences for host plants: *E. saccharina* on *C. dives*, *Sc. mesophaea* on *C. latifolius* and *Sesamia* nov. sp. 12 on *T. capensis*.

6.3.1.2 Parasitism of stem borers

Four parasitoid individuals were collected from a total of 264 stem borer specimens during this study, which represents a parasitism rate of 1.5%. The stem borer hosts could not be identified as they died due to parasitism and reliable identifications can only be made on adult specimens (Maes, 1998). Two of the parasitoids collected were Hymenoptera and two were Diptera. The hymenopteran parasitoids were collected from stem borers feeding on *P. australis* and *C. solidus,* and the species identifications are given in Table 6.5. The dipteran parasitoids were collected from stem borers feeding on *T. capensis,* and are awaiting identification at the ARC-PPRI Biosystematics Division in Pretoria.

Table 6.5 Hymenopteran parasitoids recovered from stem borer larvae collected during surveys of wild host plants in wetlands.

Parasitoid species	Host plant species of stem borer host	Farm
Dolichogenidea sp. (Hymenoptera: Braconidae)	*Phragmites australis*	Waterfall
Cotesia sp. (Hymenoptera: Braconidae)	*Cyperus solidus*	Bonnieblink

6.3.1.3 Stem borer incidence and damage in wild host plants

Stem borer infestation and damage varied throughout the year, with a major peak in mid-summer and a smaller peak in April (Figure 6.3). Changes in stem borer infestation generally mirrored changes in stem borer damage levels (Figure 6.3). The percentage of stems damaged was

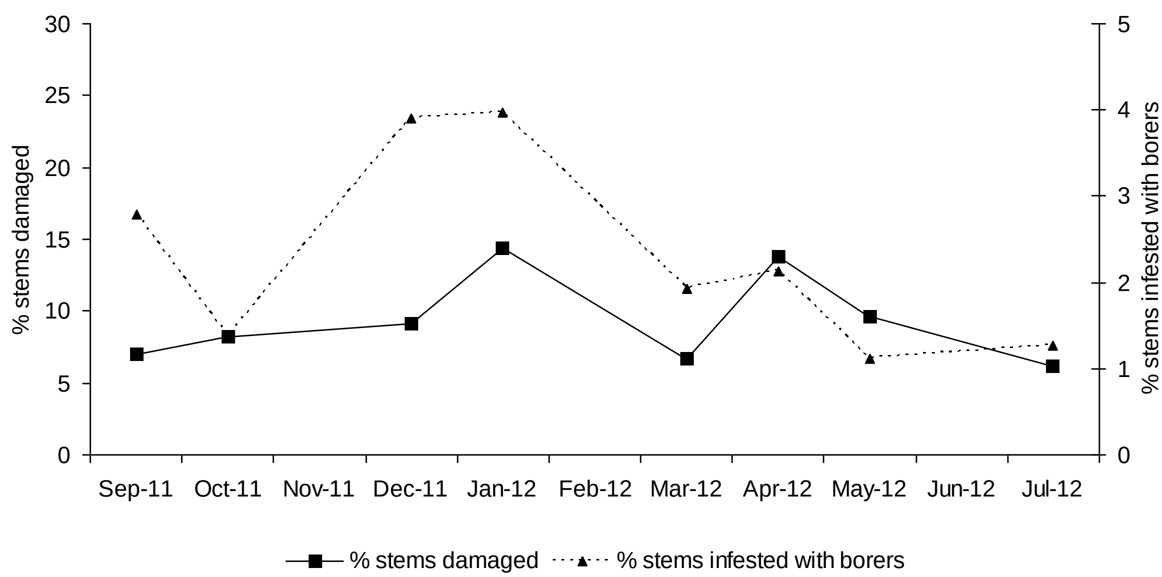

Figure 6.3. Stem borer damage and incidence on host plants across all sites, host plants and stem borer species.

significantly higher in December and January than in other months at Waterfall (Kruskal-Wallis test: $H(7) = 17.531$, $p = 0.014$) and Tweefontein (Kruskal-Wallis test: $H(7) = 16.773$, $p = 0.019$) (Figure 6.4 B). The damage levels in particular showed clear peaks, one in summer and one in autumn at Waterfall, Tweefontein and Bonnieblink (Figure 6.4 A). However, at Wanderer's Rest damage and infestation levels were generally lower than on the other farms and showed only an autumn peak (Figure 6.4). Individual host plant species also showed seasonal peaks in damage levels (Figure 6.5). Although the timing of peaks in *C. latifolius* and *T. capensis*, which were both sampled on all farms, varied, these two host plants showed summer and autumn peaks in most cases (Figure 6.5 A,B,G,H).

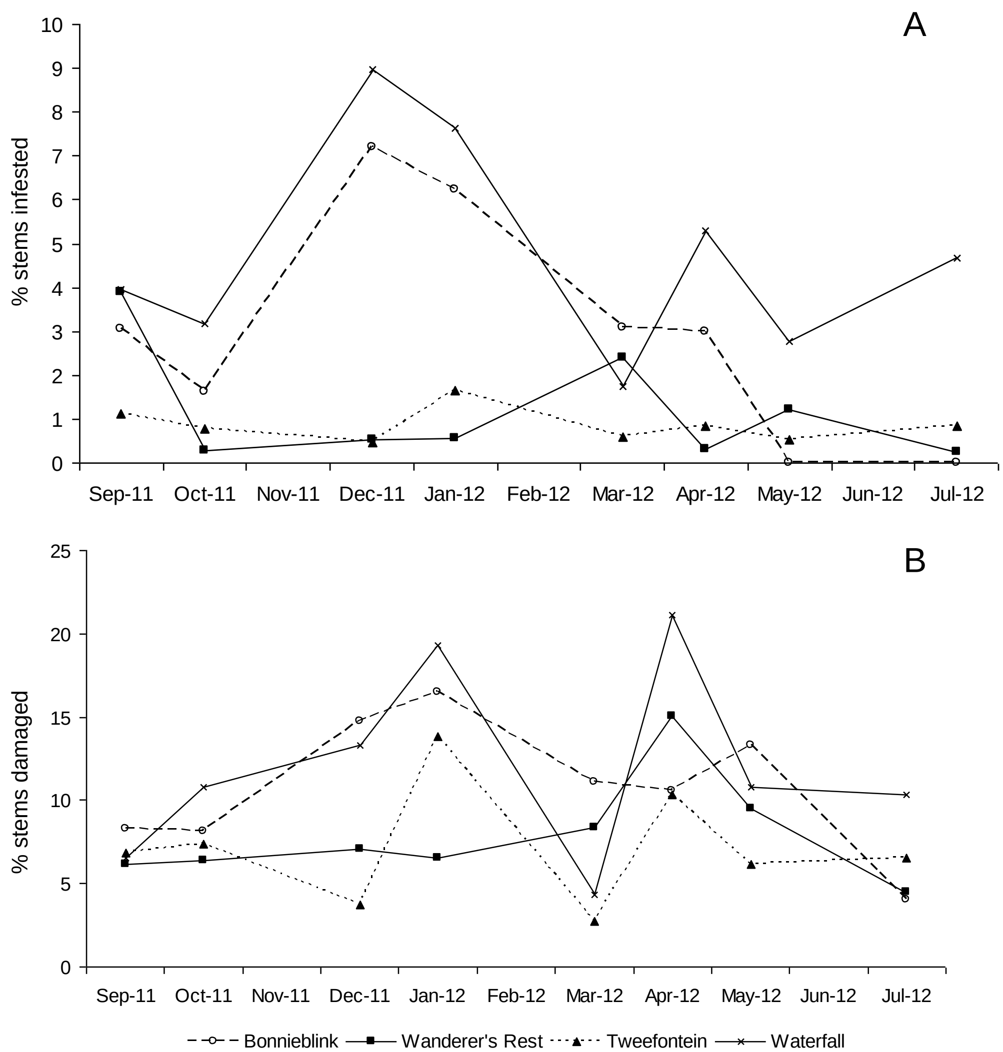

Figure 6.4. Total stem borer infestation (A) and % stems damaged (B) of all host plants sampled per farm between September 2011 and July 2012.

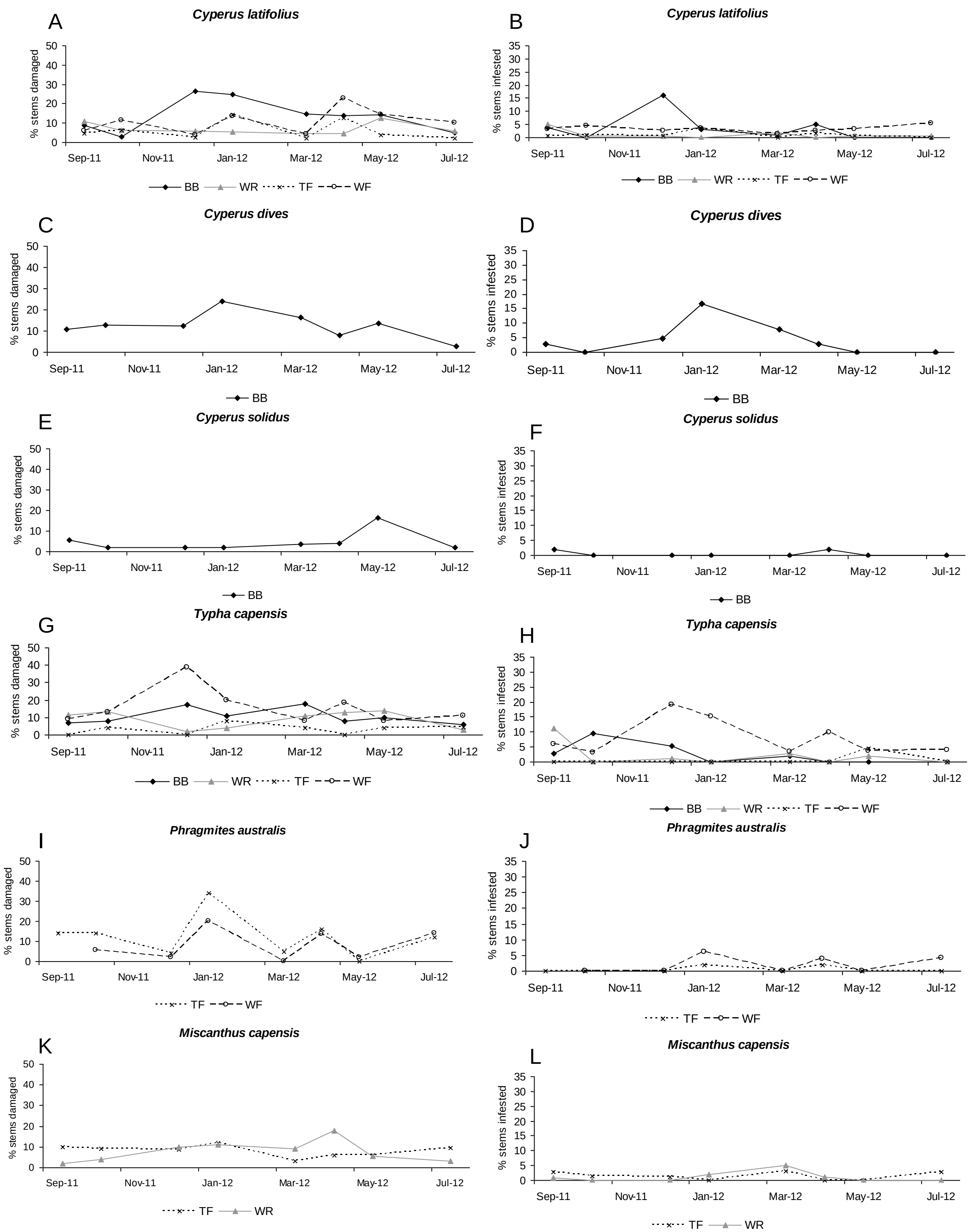

Figure 6.5. Damage and infestation levels of stem borers per host plant over the entire sampling period. Graphs on the left indicate % stems damaged, those on the right indicate % stems infested with borers. Farm names: BB: Bonnieblink, WR: Wanderer's Rest, TF: Tweefontein, WF: Waterfall.

Borer damage and infestation levels varied per farm (Figure 6.4). Waterfall had significantly higher levels of borer infestations than all other farms (Kruskal-Wallis test: $H(3) = 37.987$, $p = 0.000$, mean rank = 171.194) (Figure 6.4 A), and Tweefontein had the lowest infestation levels (Kruskal-Wallis test mean rank = 103.949) (Figure 6.4 A). Borer infestation levels also varied significantly between host plants (Kruskal-Wallis test: $H(6) = 18.058$ $p = 0.006$) (Figure 6.6). In the Kruskal-Wallis test, *T. capensis* had the highest mean rank (149.029), followed by *C. dives* (130.667) and *C. latifolius* (128.626) (Figure 6.6). *Cyperus dives* reached the highest peak of infestation and damage in the January survey (Figure 6.5 C,D) and *T. capensis* and *C. latifolius* both reached peaks in borer infestations higher than in all other host plants in the December survey (Figure 6.5 A,B,G,H). *Phragmites australis* showed a peak in borer damage levels in the January survey, and another clear peak in April (Figure 6.5 I). The host plants in the Poaceae, *M. capensis* and *P. australis,* generally showed the lowest levels of stem borer damage and infestation. *Cyperus fastigiatus* Rottb. (Cyperales: Cyperaceae) showed negligible damage levels throughout, and not a single borer was found in this species during the study, so it was removed from the analysis.

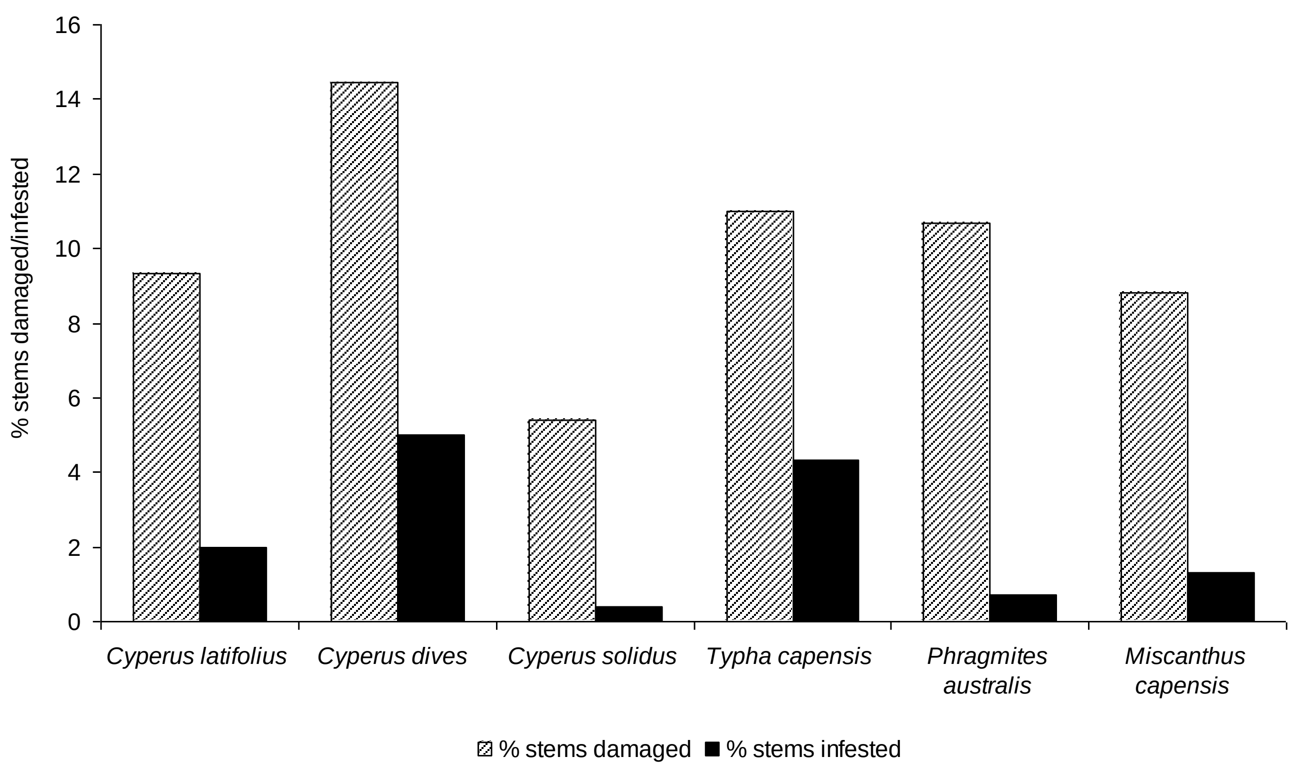

Figure 6.6. Total stem borer damage and infestation for each host plant species sampled over the entire sample, and for all farms.

6.3.1.4 *Eldana saccharina* in wetland host plants

Eldana saccharina was found almost entirely in *C. dives*. Out of a total of 47 specimens of *E. saccharina* collected from wild hosts, only two were collected from *C. latifolius*, which was growing intermingled with *C. dives* in the wetland at Bonnieblink. *Eldana saccharina* was not collected from any of the other host plants sampled, and was only found on Bonnieblink farm. The phenology of *E. saccharina* in *C. dives* is very similar to that described in other wild hosts (Conlong, 1990), in that a large population peak in immature stages was observed in the summer months (Figure 6.7). The damage levels further indicate another smaller peak in autumn which was not observed in borer levels. Levels of *E. saccharina* infestation on *C. dives* mirrors its damage levels, which indicates that *E. saccharina* is the dominant stem borer species infesting this species (Figure 6.7).

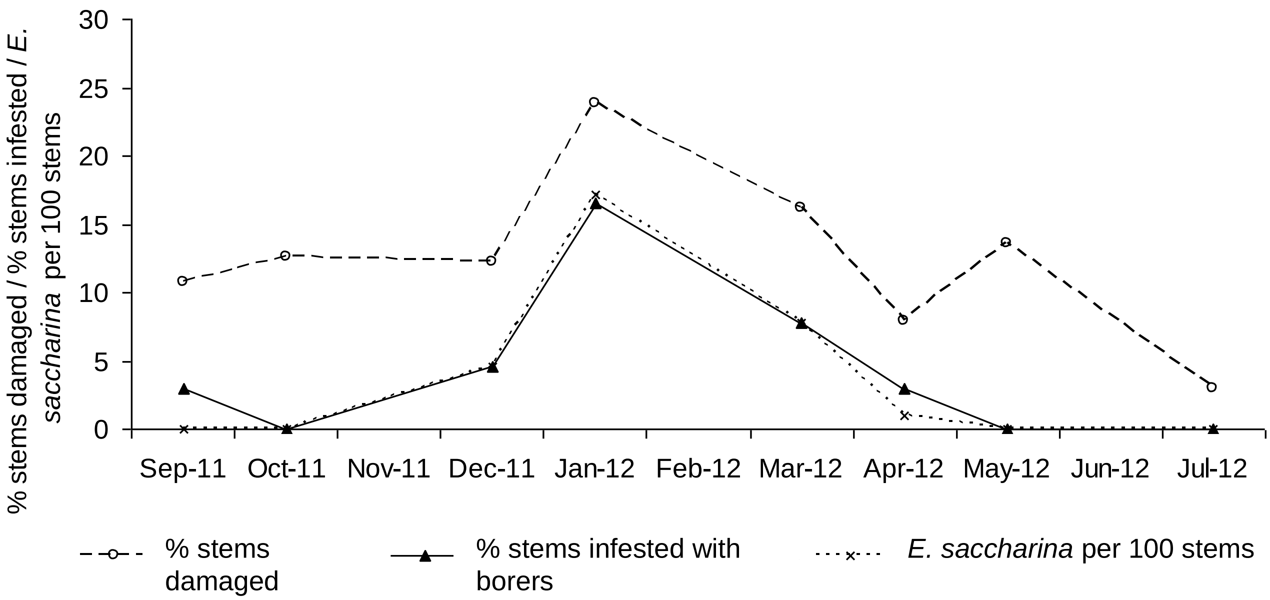

Figure 6.7. Stem borer infestation and damage on C. dives, including number of *Eldana saccharina* per 100 stems.

6.3.2 Wetland assessments

6.3.2.1 WET-Health wetland assessments

The WET-Health assessments completed on three of the farms indicated that wetlands were not in pristine condition (Table 6.6). Cloudhill and Waterfall wetlands were both found to be largely modified, and the Tweefontein wetlands moderately modified. Impacts on hydrology and vegetation varied between farms (Table 6.6). Tweefontein had the lowest hydrological impacts, whilst Cloudhill and Waterfall both scored 3.5 out of a maximum of 10 for hydrological impacts, which is classed as moderate hydrological impact. The highest impact on vegetation was found at Waterfall, with a score of 7.5, which indicates a serious impact, due to large modifications on the functioning of the

Table 6.6. Assessments of wetlands on the farms used in the study using WET-Health criteria (Macfarlane *et al.*, 2007) and recommended actions (Koopman pers. comm.) (Maps: Appendix G)

	Cloudhill	**Waterfall**	**Tweefontein (2 sites)**
Wetland type	Palustrine wetland: Valley-bottom, channelled	Palustrine wetland: Valley-bottom, unchannelled	Hillslope seepage, linked to a stream
Hydrological impacts	moderate (C) & large (D) total score=3.5	serious (E) & critical (F) total score=3.5	Wetland 1: small (B) Wetland 2: small (B) total score=(1.0+1.0)/2=2.0
Vegetation impacts	large (D), serious (E) & critical (F) total score= 7.3	critical (F) (including drains) total score=5.8	Wetland 1: moderate (C) Wetland 2: large (D) total score=(3.0+4.3)/2=3.7
Overall score & PES	5.8 Largely modified (D)	4.9 Largely modified (D)	3.0 Moderately modified (C)
Dominant alien invasive plant (IAPs) species (in order of abundance)	*Lantana camara* L. (Lamiales: Verbenaceae) *Rubus cuneifolius* Pursh (Rosales: Rosaceae) *Morus alba* L. (Rosales: Moraceae) *Solanum mauritianum* Scop. (Solanaes: Solanaceae) *Eucalyptus grandis* W. Hill ex. Maiden (Myrtaceae: Myrtales)	*Rubus cuneifolius* *Acacia mearnsii* De Wild. (Fabales: Fabaceae) *Paspalum urvillei* Steud. (Cyperales: Poaceae)	*Acacia mearnsii* *Lantana camara* *Solanum mauritianum*
Immediate recommended rehabilitation action (V=vegetation actions, H=hydrological actions)	V: clear IAPs in priority areas: e.g. stream crossings & establish *Cyperus dives* & *Cyperus papyrus* (protect from grazing cattle) (map: V1,V2) H: none	V: continue with IAPs clearing programme and establishment of *C. papyrus* & *C. dives* throughout wetlands, especially at stream crossings (map: V1, V2 etc) H: plant *C. dives* & *C. papyrus* in least functioning drains (map: H1)	V: clear IAPs in priority areas: stream crossings (map: V1, V2) & establish *C. dives* & *C. papyrus* H: none
Long-term recommended rehabilitation action	V: Clear all IAPs, including large woody trees to reduce erosion in stream bed. Maintain wetland areas clear of IAPs H: Clearing of large woody trees from stream bed will slow flow and improve hydrological functioning (e.g. map H1)	V: Keep all IAPs out of wetlands, continue establishment of *C. papyrus* & *C. dives* H: monitor changes in drainage where *C. dives* & *C. papyrus* were planted. Consider taking field H2 out of production and rehabilitating by blocking drains e.g. by planting sedges.	V: Clear all IAPs, including large woody trees to reduce erosion in stream bed. Maintain wetland areas clear of IAPs, continue establishment of *C. papyrus* & *C. dives* H: Clearing of large woody trees from stream bed will slow flow and improve hydrological functioning (e.g. map H1, H2)

wetland by extensive drains and one large and three small dams in the wetland. All wetlands had alien invasive plants (IAPs) growing in them, although the species composition and extent and intensity of the infestations varied (Table 6.6). Details of recommendations on wetland rehabilitation and management given to farmers are discussed in section 6.4.3 below.

6.3.2.2 Assessment of wetlands for suitability as *Eldana saccharina* habitat

All five wetlands were assessed for their suitability as potential habitat for *E. saccharina* (Table 6.2, Figure 6.1). *Cyperus dives* was present in wetlands at Bonnieblink, Wanderer's Rest and Waterfall Table 6.7). The populations at Bonnieblink and Wanderer's Rest were naturally occurring, whereas the plants at Waterfall had been planted specifically for *E. saccharina* management. Waterfall is however on the margin of the natural range of this species, as it lies at an altitude of 983m (Table 6.2), and C. dives occurs only up to 1000m. The largest population of *C. dives* was found at Bonnieblink, which is also where *E. saccharina* was found infesting this host plant (Figure 6.7). Despite Cloudhill being situated at a suitable altitude for *C. dives* establishment, there was no naturally occurring population of this species at Cloudhill, likely due to poor wetland health. Tweefontein is also on the margin of *C. dives* distribution (906m, Table 6.2), and no natural *C. dives* was found there. The farmer has planted *C. dives* on two occasions but it seems to have been outcompeted by *C. latifolius* (personal observations).

Table 6.7 Factors contributing to the suitability of wetlands as habitat for *Eldana saccharina* on farms.

	Farm				
	Bonnie-blink	Wanderer's Rest	Tweefontein	Waterfall	Cloudhill
Current suitable area and % of total sugarcane area	0.39ha (0.72%)	0.07ha (0.04%)	0.00ha (0%)	0.50ha (0.12%)	0.01ha (0.01%)
Potential suitable area and % of total sugarcane area	0.59ha (1.09%)	0.72ha (0.49%)	1.86ha (1.90%)	18.04ha (4.30%)	2.17ha (3.06%)
Current suitable host plants	Extensive *C. dives (natural)*	*C. dives (natural)* Some *C. papyrus (planted)*	negligible	Some *C. dives* and *C. papyrus (both planted)*	Some *C. papyrus (planted)*

Cyperus papyrus was not found growing naturally on any of the farms. However, populations planted at Wanderer's Rest, Waterfall and Cloudhill appear to be growing well (Table 6.7). Observations on Waterfall farm have shown that *C. papyrus* grows to a larger biomass much quicker than *C. dives* does (T. Webster, pers. comm. 2012), which may make it more suitable in habitats where *C. latifolius* is dominant and may compete.

On all farms, there are large suitable wet areas which could potentially sustain populations of either or both *C. dives* and *C. papyrus* (Table 6.7). Bonnieblink is the nearest to reaching its full potential in terms of the extent of the wetland utilized for *C. dives* (current: 0.39ha, potential: 0.59ha, Table 6.7), and more *C. dives* and *C. papyrus* could still be planted in large areas of wetlands on the other farms to increase the available habitat for *E. saccharina*. Waterfall has the largest potential area available for establishment of sedges (18.04ha, Table 6.7), and this is due to the topography of the farm and the nature of the wetlands. The wetlands on Waterfall are palustrine wetlands, with lots of permanently wet zones suitable for sedges (DWAF, 2005). Currently these areas are dominated by *C. latifolius* and *T. capensis*, and successful establishment of *C. dives* at this high altitude may be difficult.

Cloudhill also has relatively large area available for potential establishment of *C. dives* and *C. papyrus* (2.17ha, Table 6.7), and since it is located in an area where *C. dives* occurs naturally, the species should establish well in this wetland once IAPs have been cleared. Tweefontein has 1.86 ha available (Table 6.7), and here, as for Waterfall, planting *C. dives* in areas dominated by *C. latifolius* may be problematic. The farmer at Wanderer's Rest has already planted a lot of *C. papyrus* and *C. dives*, but there is still over half a hectare of area suitable for further planting of these species (Table 6.7).

6.4 Discussion

6.4.1 Stem borer ecology in wetlands

Nine species of stem borer were found in wetlands on the sugarcane farms in this study (Table 6.4). The diversity of stem borers was thus higher in the wetlands than in crops on these farms, and this is consistent with other studies (Le Rü *et al.*, 2006a; Le Rü *et al.*, 2006b; Mailafiya *et al.*, 2011). During the push-pull field trials reported in Chapter 5, only two stem borer species were found in sugarcane fields (*Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *E. saccharina*), and unpublished data of a survey in maize fields in the same area identified three stem borer species in maize: *S. calamistis*, *B. fusca* and *C. partellus* (J. Cockburn, unpublished data). The only economically important species of stem borer found in the wetlands was *E. saccharina,* despite the fact that *S. calamistis*, *B. fusca* and *C. partellus* were found infesting crops in the vicinity. This is unsurprising, as populations of economically important stem borers are known to often reach much higher levels in crop plants than in wild hosts (Gounou and Schulthess, 2004; Matama-Kauma *et al.*, 2008).

Parasitoid diversity is likely also to be higher in the wetland host plants than in the crop plants, as has been found in other studies (Mailafiya *et al.*, 2011). In Chapter 5, it was shown that parasitoids were found only on *S. calamistis* in sugarcane (Chapter 5, Table 5.6). The rate of parasitism was 6.5% for *S. calamistis* and 0% for *E. saccharina,* compared to 1.5% overall parasitism of wetland stem borers*.* Two hymenopteran parasitoid species were found in wetlands: *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae), which is known to parasitize *S. calamistis* (Bosque-Pérez and Schulthess, 1998; Conlong, 2000; Kfir *et al.*, 2002), and one specimen of *Stenobracon* sp. In contrast, four parasitoid species, from the orders Diptera and Hymentoptera (Table 6.5), were recovered from stem borers in wetlands (identity of dipteran parasitoids to be confirmed). Of interest is the parasitoid from the genus *Dolichogenidea* which was collected from an unidentified stem borer in *P. australis.* Moolman *et al.* (2012) also found *Dolichogenidea* sp. attacking numerous stem borer species, including some using *P. australis* as a host. Species from this genus have previously been found to parasitise *E. saccharina*, once in maize in Benin (Conlong, 2000) and once in *C. dives* in Ethiopia (Assefa *et al.*, 2006). Although *Dolichogenidea polaszeki* Walker (Hymenoptera: Braconidae) failed to establish on *E. saccharina* in the laboratory in South Africa (Conlong, 2000), its presence in wetlands on sugarcane farms is encouraging, and supports the importance of wetlands as a potential habitat for natural enemies of *E. saccharina.* Similarly, the *Cotesia* sp. parasitoid found in *C. solidus,* which is from the same genus as *Cotesia sesamiae* which is known to infest *S. calamistis* in sugarcane (Conlong, 2000), indicates that the natural enemies of *S. calamistis* may be using alternate hosts in wetlands. This information on stem borers species, their host plant associations and parasitoids makes an important contribution to knowledge of wild stem borers in southern Africa, which is currently scarce (Le Rü *et al.*, 2006a; Le Rü *et al.*, 2006b; Moolman *et al.*, 2012). Furthermore, it provides insight into potential sugarcane stem borer invaders should the wetland habitats become degraded, and the indigenous host plant populations depleted.

Scrutiny of the stem borer species found in wetlands and a study of ecological information in the literature indicates that that there is a lack of knowledge of these species. Two new species were found which have not yet been described (*Sesamia* nov. sp. 12 and *Sesamia* nov. sp. 16, Table

6.4). In his study of wild stem borers in South Africa, Moolman (2011) found *Sesamia* nov. sp. 12 infesting *P. australis* and *T. capensis*. Two of the noctuid species found are widespread, highly polyphagous species, namely *P. piscator* and *Sc. mesophaea* (Moyal *et al.*, 2010). *Pirateolea piscator* is polyphagous (feeds on Poaceae and Cyperaceae), occurs mostly between sea level and 2297m, and is found in many different vegetation mosaics/habitats in eastern and southern Africa (Moyal *et al.*, 2010). It has also previously been found in maize (Ong'amo *et al.*, 2006). According to Le Rü *et al.* (2006b), *P. piscator* is a potential threat to cereal crops since it has been found on maize in the field, and can complete development on maize in the laboratory. This species has also been recorded feeding on sugarcane (Moyal *et al.*, 2010). *Sciomesa mesophaea* is also polyphagous, feeds on many species of the Cyperaceae and Typhaceae, is found between 850m and 2119m, in many different vegetation mosaics or habitats in eastern and southern Africa (Moyal *et al.*, 2010). Although there is no record of this species attacking cultivated crops as yet, its widespread distribution and polyphagous nature indicates that it could undergo a host shift to cultivated crops, as other indigenous lepidopteran stem borers have done (Atkinson, 1980; Polaszek and Khan, 1998). The fact that multiple specimens of both *P. piscator* and *Sc. mesophaea* were reared on artificial diets made of crushed maize leaves confirms their tolerance of a wider range of host plants. Knowing that *E. saccharina* moved from indigenous wetland host plants onto sugarcane (Atkinson, 1980), the presence of *P. piscator* and *Sc. mesophaea* in wetlands in the sugarcane agroecosystem should not be discounted as a threat to biosecurity. The destruction of wetlands to make way for sugarcane fields was suggested as the driving force behind movement of *E. saccharina* into a new habitat, and if the wetlands which remain are not protected, there is a possibility that stem borers such as *P. piscator* and *Sc. mesophaea* could undergo a similar host switch in the cooler midlands area.

The remaining stem borer species found in wetlands generally have more specific host plant requirements, i.e. they are monophagous or oligophagous (Bernays and Chapman, 1994). *Speia vuteria* seems to prefer host plants from the Typhaceae family. In South Africa it has almost only been only found on *T. capensis* (Govender *et al.*, 2011; Moolman, 2011), except for one record on *Triticum spp*. (Taylor,1957 in (Kroon, 1999). In Kenya it was found on *Typha domingensis* (Le Rü *et al.*, 2006b). According to Moolman (2011), *S. vuteria* is associated with lower altitudes, below 200m. However, we found it at Bonnieblink farm (606m) and at Waterfall (983m), at much higher altitudes than suggested by Moolman (2011). *Sesamia incerta* and *C. sesamoides* were both only found on one plant species in the present study. *Sesamia incerta* was found on *P. australis* in this study and also by Moolman (2011). *Conicofrontia sesamoides* was found on *M. capensis* in this study and by Moolman (2011), who also found it on *Cymbopogon* sp.

Five of the nine stem borer species found in this study were also collected by Moolman *et al.* (2012). They completed a much more extensive study, in which only host plants showing signs of damage for stem borers were sampled, to increase numbers of stem borers collected. Their study recorded parasitism on all five stem borer species collected in wild host plants in this study: *P. piscator, Sc. mesophaea, S. incerta, Sesamia* nov. *sp. 12 and C. sesamoides.* This illustrates the importance of indigenous habitats for multi-trophic interactions, which provide biological control of stem borers. The overall parasitism rate of 1.5% found in the present study falls within to the range of stem borer parasitism recorded by Mailafiya *et al.* (2011) in natural habitats (0.5-8%).

Stem borer incidence and damage showed seasonal variations, with a major peak in summer and a minor peak in autumn in some host plant species (Figure 6.5). The peaks in stem borer damage in *C. dives*, mostly due to *E. saccharina*, were very similar to those reported by Conlong (1990) for the same borer species in *C. papyrus*.

The highest diversity of stem borer species in one wetland was found at Waterfall (6 species), followed by Bonnieblink (3 species) and Tweefontein (3 species) (Table 6.4). Waterfall has the largest potential stem borer habitat (18.04ha, Table 6.7) and this may explain why it has the highest stem borer diversity, and also high stem borer abundance compared to other sites. In contrast, at Wanderer's Rest the low species diversity (Table 6.4), absence of a summer peak and generally low levels of stem borer infestation and damage (Figure 6.4) may indicate that this wetland is a less stable habitat than the other three sites. This wetland is more riparian in nature than the other wetlands, and there is a much smaller possible area in which wild host plants such as sedges could become established than for example at Tweefontein or Waterfall (Table 6.7). Based on preliminary analysis of soil types, the wetland is also reduced from what its natural extent would have been (Koopman pers. comm., 2012). This indicates that the wetland habitat at this site has been fragmented, and the size of natural habitat fragments within modified ecosystems such as farms is known to have an impact on the composition and ecology of indigenous species (Tscharntke, 1992; Elzinga *et al.*, 2005). Whether the difference in stem borer population levels and peaks at Wanderer's Rest is due to the fragmented nature of the habitat is unknown, and further studies are needed to confirm this and to link wetland health to stem borer and parasitoid populations.

Stem borer infestation and damage varied between farms (Figure 6.4) and host plant species (Figure 6.5, 6.6). The total percentage stems infested ranged from 0.4% in *C. solidus*, to 5.0% in *C. dives*. These rates of infestation are similar to those reported from wild host plants by Matama-Kauma *et al.* (2008) in Uganda, where mean infestation rates ranged from 2.0% to 10.8%. The maximum damage in *C. dives*, due to *E. saccharina*, reached 5.0% in the summer population peak (Figure 6.7). In comparison, *E. saccharina* infestations in nearby sugarcane during the same time period ranged from 0.6% (Wanderer's Rest) to 8.9% (Cloudhill) of stems infested (Chapter 5, Figure 5.3). The maximum infestation level in wild host plants is therefore almost half of the maximum percentage stems damaged in sugarcane. Lower infestations of stem borers in wild hosts than on crops have been reported in similar studies (Mazodze and Conlong, 2003; Gounou and Schulthess, 2004; Ong'amo *et al.*, 2006; Matama-Kauma *et al.*, 2008), and this difference in maximum infestation levels between sugarcane and *C. dives* confirms that *E. saccharina* reaches higher numbers in sugarcane than in wild hosts, which is likely due to higher rates of parasitism in wild host plants (Conlong, 1990).

6.4.2 Wetland assessments

The wetlands assessed in this study were all in a modified condition and therefore do not provide as much potential habitat for stem borers, particularly *E. saccharina*, as they could. If farmers were to follow the recommendations made in this study, they could increase habitat available for *E. saccharina* in the wetlands on their farms, which would provide a strong "pull" for egg-laying *E. saccharina* moths and thus reduce oviposition in sugarcane (Kasl, 2004). Further research is however required to determine the proportion of wetland habitat in relation to total sugarcane habitat to effectively reduce the number of *E. saccharina* in the crop to below an economically damaging level.

Clearing of IAPs from wetland areas is a costly management activity (Turpie *et al.*, 2008). Research has shown that IAPs have numerous negative economic and ecological impacts on catchments (Le Maitre *et al.*, 2000; Chamier *et al.*, 2012), and that removal of IAPs, although costly, has economic benefits through improved water quantity and quality (van Wilgen *et al.*, 2001; Turpie, 2004). Detailed studies quantifying the economic value of wetlands for reducing the effect of *E. saccharina* on the sugarcane crop may provide additional incentives for farmers to invest in their wetlands by removing IAPs, over and above improving water flow and quality. The importance of valuation of such ecosystem services is widely recognised (de Groot *et al.*, 2002; Brauman *et al.*, 2007).

Planting *C. dives* and *C. papyrus* for *E. saccharina* habitat management is currently being promoted in the Midlands North area (Webster *et al.*, 2005; Webster *et al.*, 2009). However the altitudinal and climatic habitat requirements of these indigenous host plant species may mean that they do not establish significant populations in the cooler parts of the region. *Cyperus latifolius* and

C. dives have similar habitat requirements as they are both obligate wetland plants (DWAF, 2005), but *C. latifolius* is generally found at higher altitudes and in cooler temperatures than *C. dives* (DWAF, 2005). Thus, successful establishment of *C. dives* populations in higher altitude wetlands, where *C. latifolius* is dominant, may be problematic. *Eldana saccharina* is adapting to cooler inland climates and its range is increasing inland (Webster *et al.*, 2009). Further research into suitable host plants for *E. saccharina* in areas beyond the natural range of *C. dives* and *C. papyrus* is needed. The long-term effects of climate change on the distribution of *E. saccharina* together with its natural host plants also warrants further investigation.

6.4.3 Recommendations to farmers for wetland management

The recommendations to farmers on how to manage wetlands for improved hydrological functioning and for stem borer habitat management emphasized habitat provision for the sedges *C. dives* and *C. papyrus* by clearing IAPs. By following the recommendations based on the WET-Health assessment (Table 6.6, Appendix G) together with the suggestions on increased planting of *C. dives* and *C. papyrus* as described in section 6.3.2.2 and Table 6.7 above, farmers can ensure improved wetland health. Overall wetland health will directly translate into benefits for *E. saccharina* habitat management, through increased habitat for its wild host plants.

The 'Push-pull wetland action plan' (Appendix H) was developed based on these wetland assessments. It is designed as a tool for farmers to use in assessing their farms and taking action for improved hydrological functioning and *E. saccharina* management. It will be made available to farmers through SASRI's extension specialists and will be included in an internal report at SASRI and a push-pull information sheet.

6.4.4 Value of wetlands in sugarcane agroecosystems

Surveys revealed a high diversity of stem borers in wild host plants in wetlands – much higher than the diversity in the sugarcane crop, and also indicated that parasitoid diversity may be higher in wild habitats. Two species of stem borer were collected in the wetlands which pose potential threats to sugarcane: *P. piscator* and *Sc. mesophaea*. The destruction of such habitats could potentially increase the threat of stem borers becoming pests of cultivated crops such as sugarcane.

The information on stem borer and parasitoid ecology from this study and others mentioned above, illustrates the important role of wetlands in regulating pest species in agroecosystems. Pest regulation is recognised as an important ecosystem service in agroecosystems (de Groot *et al.*, 2002; Bianchi *et al.*, 2006; Zhang *et al.*, 2007), but not much attention has been paid to its specific value in managing *E. saccharina* in sugarcane. Economic and cost-benefit studies are required to value and quantify the contribution which well-managed wetlands can make to controlling *E. saccharina*. The synergistic effects of managing pests and hydrological functions through good wetland management need to be explored further, as they hold potential to promote not only wetland management for regulatory and functional ecosystem services purposes, but also for the conservation of biodiversity. Wetlands provide ecosystem services beyond just the functional and habitat roles they play: they provide cultural and social services to people and have aesthetic value (de Groot *et al.*, 2002; MA, 2003). For example, a farmer in the Midlands North region described how rehabilitating wetlands on his farm has brought back wildlife such as antelope and small predators, and his description clearly showed how seeing these animals on his farm brought him pleasure. When working with farmers to conserve and manage wetlands, one needs to recognise that farming is a lifestyle in addition to an income generating activity, and some decisions made by farmers may be based on 'what they believe is the right thing to do' (Vanclay, 2004). Farmers don't differentiate decisions based on whether they serve the environment or their production goals: these goals are inextricable for farmers (Vanclay, 2004) and extension approaches to aspects such as wetland management need to recognise this, as has been mentioned in Chapter 4.

Multiple studies have demonstrated the importance of natural vegetation and on-farm biodiversity for the stability of agroecosystems (Altieri and Nicholls, 2004; Gurr *et al.*, 2004a; Bianchi *et al.*, 2006; Tscharntke *et al.*, 2007; Tscharntke *et al.*, 2012). Conserving and managing habitats for control of stem borers, in particular *E. saccharina*, is an example of such agroecological approaches to farm management. Diverse agroecosystems are more stable and resilient, especially for regulation of pest and disease outbreaks (Altieri and Nicholls, 2004; Bianchi *et al.*, 2006). The lower levels of *E. saccharina* infestation and damage in small-scale sugarcane fields has been hypothesized to be a result of the heterogenous vegetation mosaic present in small-scale grower areas (Draper and Conlong, 2000; Way *et al.*, 2003), and confirms the importance of vegetation diversity in regulation of pest populations. This is particularly important for an indigenous pests such as *E. saccharina* which does have natural enemies in the environment (Conlong, 1990; Conlong, 1994b, 2000), all that is needed is to enhance their efficacy (Conlong and Kasl, 2000; Landis *et al.*, 2000).

6.5 Conclusion and recommendations

This study has attempted to demonstrate the value of wetlands in managing *E. saccharina* on sugarcane farms. Wetlands provide a habitat for stem borers where they are controlled naturally by indigenous parasitoids, and destruction of such habitats may thus increase the threat of stem borers in the crop. After assessing the wetland health and suitability of wetlands for *E. saccharina* habitat, specific guidelines have been given to farmers on how best to rehabilitate and manage these wetlands for improved hydrological functioning, and to maximize the pest regulatory ecosystem services which these habitats can provide. These case studies provided the basis for development of a tool, the “Push-pull wetland action plan” which will be made available to all farmers in the sugar industry to aid them in managing their wetlands.

This study has highlighted some important directions for further research. Although basic research on the ecology of *E. saccharina* and its parasitoids has been completed (Conlong, 1990; Conlong, 1997a; Conlong and Kasl, 2001), there is a need to extend this research to a landscape level where the size of habitat fragments needed for effective control of *E. saccharina* by its natural enemies is determined (Tscharntke *et al.*, 2002; Elzinga *et al.*, 2005). The links between wetland health and biodiversity of stem borers and their parasitoids also need to be considered. The population dynamics and migration of *E. saccharina* between crop and wild host plants need further research. The outcomes of this research will aid in valuing the pest regulatory ecosystem services which wetlands on sugarcane farms provide, and therefore provide further motivation for farmers to spend money on costly clearing of IAPs and other wetland management activities.

It is clear that knowledge of *E. saccharina*’s host plants and their ability to establish substantial populations in cooler upland areas is insufficient. In promoting a habitat management approach to controlling *E. saccharina* through the use of push-pull, an understanding of the habitat requirements of push-pull plants is crucial. Although there is need for further research, the concept of wetlands providing pest regulatory ecosystem services on sugarcane farms has been demonstrated in this study. The push-pull adoption network in Chapter 4 emphasized the need for farmers to effectively manage wetlands to be able to implement push-pull successfully. By providing farmers with a tool to manage wetlands on their farms and maximize these ecosystem service benefits for crop protection, it is hoped that implementation of push-pull for the sustainable control of *E. saccharina* will continue to increase in the Midlands North, and will spread to other regions of the South African sugar industry.