SRA Research Project Final Report

(Please note: The report must be submitted as a Word document)

SRA Project Code	**2011342**
Project Title	Remote sensing to implement an effective pest management strategy for canegrubs
Key Focus Area in SRA Strategic Plan	Pest, disease and weed management
Research Organisation(s)	SRA Limited, UQ
Chief Investigator(s)	Nader Sallam, SRA Limited, Meringa, Cairns
Project Objectives	- Develop a remote-sensing system that can identify canegrub infestations - Develop a web-based system to deliver early-warning information - Facilitate outputs of concurrent projects on risk assessment, cane beetle behaviour and predictive modelling
Milestone Number	9

Milestone Due Date	1/3/2015	**Date submitted**	10/6/2015

Reason for delay (if relevant)	Data analysis required more time than originally anticipated
Milestone Payment	$28,492
Milestone Title	Final Report
Success in achieving the objectives	☒ Completely Achieved ☐ Partially Achieved ☐ Not Achieved
SRA measures of success for Key Focus Area (from SRA Strategic Plan)	- Industry supported through effective pest, disease and weed diagnostic capabilities and awareness and training programs. - Development and adoption of SRA-developed packages for integrated management of key pests, diseases and weeds. - Capability to provide entomology, pathology and weed expertise to meet the pest, disease and weed diagnostic and management needs of the industry.

Section 1: Executive Summary

a) *Issue:*

The greyback canegrub (*Dermolepida albohirtum*) is the main pest of cane crops in all canegrowing regions from Mossman to Sarina. Infestations by this pest species may cost the industry up to 40 million dollars in years of high infestations. Other grub species also cause considerable damage in Southern Queensland. Canegrubs feed on the root mass of sugarcane plants reducing plant vigour and yield. Due to the annual life cycle of these pests, it is usually too late to apply pesticides to the crop by the time damage symptoms become apparent. In addition, grub numbers usually build up and initially remain unnoticed until an economical threshold is reached, at which time control measures become too costly or too late to implement. Hence, timely monitoring and early warning techniques need to be implemented to reduce the chances of pest outbreaks. Conventional field sampling is a time-consuming and strenuous task, hence, remote sensing/satellite imagery techniques may be implemented for timely damage detection and to provide advice to growers accordingly. Satellite images therefore were sourced for each participating region in the project (FNQ, Burdekin and Central district and Southern district). Geographic Object Based Image Analysis (GEOBIA) and the highly advanced "eCognition" software were used for image analysis. Based on the mapping results we then compiled grub damage risk maps which were communicated to growers.

b) *R&D Methodology:*

After a satellite image is taken for a region it is first pre-processed to correct for radiometric and geometric effects and then analyzed using GEOBIA to automatically identify areas with canegrub damage. We developed four key steps to conduct the analysis: (1) initial segmentation of block boundaries and further segmentation of each block into smaller homogenous objects; (2) classification and subsequent omission of fallow/harvested fields, tracks and other non-sugarcane features; (3) identification of potentially grub-damaged areas within each block with the lowest amounts of green leaves (low Normalised Difference Vegetation Index (NDVI) values) and highest level of image texture and (4) further refining of 'potentially' grub damaged areas into low, medium or high likelihood of an area being affected. This is based on the absolute difference in the amount of green leaves (NDVI values) and texture between 'potentially' grub damaged areas and the remaining parts of each block. Areas suspected of sustaining grub damage based on the analysis are then visited for "ground-truthing". A flight is also conducted to facilitate better examination of any apparent disorder. A ground-truthed map can then be produced and communicated to growers. False positives and false negatives are noted to further improve detection

accuracy. We conducted several GrubPlan workshops across Queensland which were attended by growers, Productivity Service and mill staff members. The project has been very well received by the industry.

c) *The project deliverables*
We developed an eCognition rule set for classifying grub damage using satellite images. We also developed the capacity to produce accurate grub damage risk maps. Our validation work yielded overall damage detection accuracies of up to 90% or higher in several cases, however, this included a number of false positives resulting from sprawling, water logging, weed and pig damage. Our damage detection accuracy can only improve as more work is conducted and more data are fed to the model. The technology is now at a stage where it can be implemented by the industry.

d) *The outcomes and impact of the project findings on the sugar industry and the Australian community.*
The project addressed the "Pest, disease and weed management" key focus area, and we believe the following measures of success have been recognized:
  o Industry supported through effective pest, disease and weed diagnostic capabilities and awareness and training programs.
  o Development and adoption of SRA-developed packages for integrated management of key pests, diseases and weeds.
  o Capability to provide entomology, pathology and weed expertise to meet the pest, disease and weed diagnostic and management needs of the industry

These criteria have been achieved through direct communication of results to Mulgrave, Burdekin, Mackay, Bundaberg and Isis industry members. We conducted several GrubPlan workshops in most areas where we communicated the results and distributed risk maps to growers and millers. During these workshops, Integrated Pest Management concepts were addressed as an all-encompassing approach to grub control and general crop health instead of only relying on pesticides. In addition, several other observations can be made via the use of a satellite image as general crop condition and potential yield could also be estimated. Currently the capacity of delivering a digital risk map to be accessed through Google Earth or the mill website is available. Most growers welcomed the information they received and expressed interest in maintaining this work. We have been in consultation with several canegrowers and Productivity Service staff across Queensland. Through these discussions, a clear image on the advisory service style required has emerged, and we are now able to produce accurate grub risk maps and provide advice on general crop condition to participating growers/mill regions according to their need. A subsequent

"industry implementation" phase of the project is ready to be rolled out in certain regions where industry members are willing to support this work financially.

Section 2: Background

The greyback canegrub (*Dermolepida albohirtum*) is the main pest of cane crops in all canegrowing regions from Mossman to Sarina (Allsopp 2010; Sallam 2011). Other grub species such as the Southern one year canegrub (*Antitrogus consanguineous*), Childers canegrub (*Antitrogus parvulus*) and Negatoria canegrub (*Lepidiota negatoria*) cause significant damage in the Southern Region (Allsopp et al 1993). Canegrubs can be detected in the field once they are large enough to be found under cane stools, however, it is then too late to apply control measures as crops become too large and inaccessible to machinery. Nevertheless, it has been proven that grub damage in one year relies on the extent of damage in the previous year. Hence, damage prediction models were developed through previous BSES/SRA projects and were well received by the industry (Sallam et al 2013; Sallam & Lowe 2012; Samson 2008; Samson & Eaton 2012; Samson et al 2007; 2011). Strategic application of pesticides is now implemented in Far North Queensland based on advice generated through the "GrubPlan" program (Sallam & Lowe 2012; Samson & Eaton 2012). However, previous monitoring and forecast methodologies relied on extensive field work (digging up cane plants, laboratory breeding of recovered canegrubs, assessment of canegrub pathogen rates etc.) which are very demanding tasks. This project addressed the potential of using remote sensing/satellite imagery technology to detect emerging grub damage and produce risk maps to advise growers.

The need for new data processing techniques became obvious after the launch of the first high spatial resolution satellite sensor (Ikonos) in 1999 and the increasing availability of satellite and airborne high spatial resolution imaging sensors and laser scanners. This also coincided with the release of "eCognition", which is the first commercially available geographic object-based image analysis (GEOBIA) software (Benz et al 2004). Since then, significant progress has been achieved in the application of remote sensing and satellite imagery for agricultural purposes. Vegetation Indices (VIs) derived from the spectral bands in multispectral imagery have long been used to estimate crop yield (Tucker et al 1980; Wiegand et al 1991; Yang and Everitt 2002). Two of the earliest and most widely used VIs are the simple NIR/Red ratio (Jordan 1969) and the Normalized Difference Vegetation Index (NDVI) (Rouse et al 1973). Remote sensing technology has also been used for pest and disease detection. For example, airborne multispectral imagery with four broad bands (blue, green, red and NIR) was used to map late blight infestations in tomato fields in California (Zhang et al 2003; 2005). While high resolution QuickBird satellite multispectral imagery and airborne hyperspectral imagery were used for detecting powdery mildew and leaf rust in winter wheat in Germany (Franke and Menz 2007). In Australia, Hyperion satellite hyperspectral imagery was used to detect orange rust disease in sugarcane fields (Apan et al 2004).

For the purpose of data interpretation, recent work showed that an "object-based approach" is the most suitable means of high spatial resolution image analysis, where clusters of pixels-forming features (i.e. a tree, a house or a patch of grub damage) are analysed instead of individual pixels (Blaschke 2010). The aim of GEOBIA is to develop and apply theory, methods and tools for replicating and improving human interpretation of remotely sensed imagery in an automated manner. GEOBIA

consists of image segmentation (i.e. clustering of pixels into homogenous objects) and subsequent classification and modelling based on the object characteristics. In addition to the statistical characteristics of the objects, GEOBIA allows the inclusion of additional contextual information properties not available in traditional pixel-based approaches. Such information may include the area, shape and texture, objects location in relation to other objects and land cover classes in the landscape (Johansen et al 2010). High spatial resolution satellite imagery can then be used to provide a bird's-eye view of cane fields and determine the location and extent of grub damage.

In this current project, it was demonstrated that cane varieties exhibit significant variations in texture; for example a smooth-textured cane variety with light grub damage may appear similar to a healthy cane variety with a rougher texture. Hence a new mapping approach was initiated using GEOBIA and the eCognition Developer 9.0 software. This allowed not only spectral and textural information to be used, but also contextual information, object shape information and analysis at multiple spatial scales. The GEOBIA mapping approach we have developed includes four key steps for the study sites in Queensland: (1) the initial segmentation of block boundaries and further segmentation of each block into smaller homogenous objects; (2) classification and subsequent omission of fallow/harvested fields, tracks and other non-sugarcane features; (3) identification of potentially grub-damaged areas within each block with the lowest amounts of green leaves (low NDVI values) and highest level of image texture and (4) further refining of 'potentially' grub damaged areas into low, medium and high likelihood of an area being affected based on the absolute difference in the amount of green leaves (NDVI values) and texture between the 'potentially' grub damaged areas and the remaining healthy parts of each block.

Section 3: Outputs and Achievement of Project Objectives

Section 4: Outputs and Outcomes

Note: The following essay reports on Sections 3 and 4 combined since both address similar criteria.

Project objectives
The project objectives according to the project agreement were to:
- Develop a remote-sensing system that can identify canegrub infestations
- Develop a web-based system to deliver early-warning information
- Facilitate outputs of concurrent projects on risk assessment, cane beetle behaviour and predictive modelling

All project objectives have been met during the course of this work. The following is an account of the methodology used, results generated, project's application and industry participation.

Materials and Methods
  Image captures

GeoEye-1 multispectral (blue, green, red and near infrared bands of 2 m x 2 m pixels) and panchromatic (0.50 m x 0.50 m pixels) images were acquired over Bundaberg (50.7 km^2); Childers (53.8 km^2); Mackay (73.3 km^2); Burdekin (51.6 km^2) and Mulgrave (127.9 km^2). Image collection dates are listed in table 1.

Table 1. Dates satellite images were captured during the course of the project.

Bundaberg	Childers (Isis region)	Mackay (Central district)	Burdekin	Mulgrave (FNQ)
6/5/12	2/4/12	4/5/12	1/4/12	4/5/12
19/6/12	19/6/12	3/6/12	4/5/12	9/6/12
25/12/12	25/12/12	26/12/12	19/12/12	18/12/12
25/5/13	25/5/13	26/5/13	27/3/13	26/5/13
25/12/13	30/12/13	14/6/13	26/5/13	17/6/13
26/4/14	18/4/14	2/5/14	17/6/13	4/6/14
			2/5/14	

As work progressed it was demonstrated that a December image did not improve damage detection in the Mackay, Burdekin and Mulgrave regions, and only one image taken before harvest when canegrub damage is most pronounced in terms of stool tipping and change in leaf colour was deemed necessary for those regions. In case of the Bundaberg and Isis districts, two images (in December and May) were needed due to the coexistence of one and two year key grub species in the Southern region. The December image was found useful for identification of areas with limited growth in relation to neighbouring areas, which was found to correspond with canegrub damage in many cases. The May image was used in a similar fashion to the more northern sites, where stool tipping, changes in leaf colour and ground exposure become characteristics to use for damage detection.

Image Orthorectification/georectification

All images were first radiometrically corrected to represent Top of Atmosphere reflectance values using the following equation:

$$P_\lambda = \frac{\pi * d^2 * ((DN_\lambda * Gain_\lambda) + Offset_\lambda)}{\cos\theta_s * Esun_\lambda}$$

Where:

λ = Specific spectral band of image (Near-Infrared, Red, Green, Blue or Panchromatic)

P_λ = Top of Atmosphere Reflectance for band λ

d = Earth-Sun distance factor (ratio of actual distance to the mean distance)

DN_λ = Digital number in image for band λ

$Gain_\lambda$ = Radiometric calibration gain (mW/cm^2/μm/str/DN) for band λ

$Offset_\lambda$ = Radiometric calibration offset (mW/cm^2/μm/str/DN) for band λ

θ_s = Solar Zenith Angle (degrees)

$Esun_\lambda$ = Mean solar exoatmospheric irradiance for band λ (mW/cm^2/μm)

Once the images were radiometrically corrected to Top of Atmosphere reflectance, the images were orthorectified. As the images were not collected over flat terrain and as the images were not collected at image sensor viewing angles at nadir, orthorectification of the images was required. For example, terrain relief of 100 m elevation within an image captured at a 20° off-nadir image sensor viewing angle will result in a horizontal displacement of 36 m. Hence, variations in horizontal displacement will vary across an image depending on terrain elevation differences. A simple spatial offset of the images is therefore not possible before the images had been orthorectified. The Shuttle Radar Topography Mission (SRTM) smoothed Digital Elevation Model (DEM) with 30 m pixels with each pixel representing terrain height above sea level was used together with the rational polynomial coefficients (RPCs) provided with the image data to orthorectify all the images. After the orthorectification process, the images were spatially matched to the existing spatial layers with sugarcane block boundaries and previously collected images. In addition, all images were also pan-sharpened, i.e. combining the high spatial resolution of the panchromatic band (0.5 m pixels) with the multi-spectral bands (2.0 m pixels) to achieve a multi-spectral image with a pixel size of 0.5 m. The Gram-Schmidt spectral sharpening process was used together with a bilinear resampling approach.

Initial Analysis of Grub Damage

Major cane varieties were identified for each study area (examples are given in figure 1), and spectral and textural properties of healthy crops were defined via ground-truthing. Plots were marked out in fields that had been identified as "canegrub-infested" and grub numbers were determined via intensive sampling (up to 20 stools per plot). Damaged areas were identified via aerial and/or ground inspection. Patches were located on the ground using GPS units and inspected for damage.
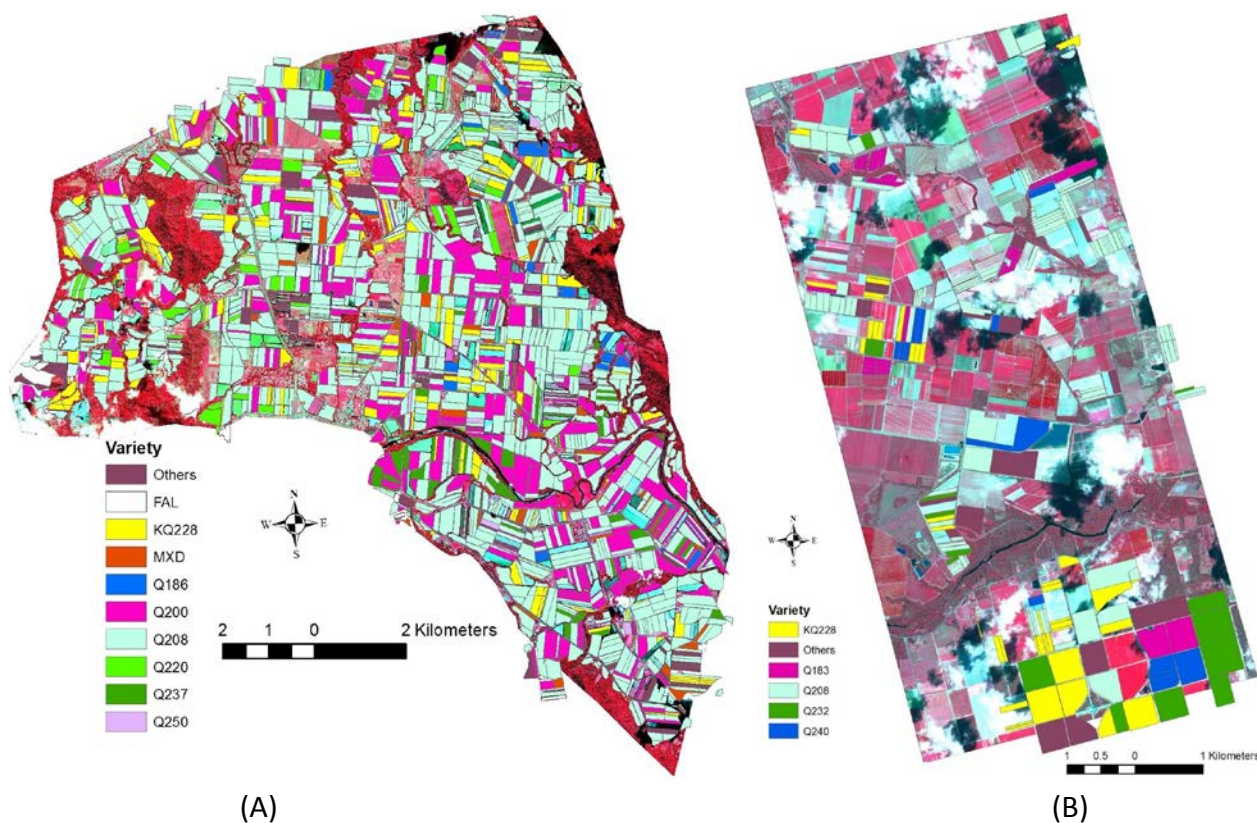
Figure 1. Dominant cane varieties in 2014 within the Mulgrave (A) and Bundaberg (B) study areas.

Classification of images utilises both spectral and texture responses from healthy and known grub-damaged areas within the image. Spectral measures consider the intensity of individual pixels intensity across different wavelengths. Textural measurements consider a neighbourhood of pixels and how pixels relate to one another (Haralick et al 1973). In our case, a single 'texture' rule could not be applied across the whole image as each variety displayed an individual 'texture signature' due to the wide range of varieties grown in each region, some in very low quantities. Therefore only major varieties were chosen from each district for initial analysis. Representative samples were then used to create "semi-variograms" for healthy and grub damaged cane. Semi-variograms identify the spatial dependence between closely located pixels. For healthy samples, a quadrat of 30x30 pixels was sampled for each variety while a quadrat of 80x80 pixels was sampled for canegrub-damaged samples (Figures 2 & 3).
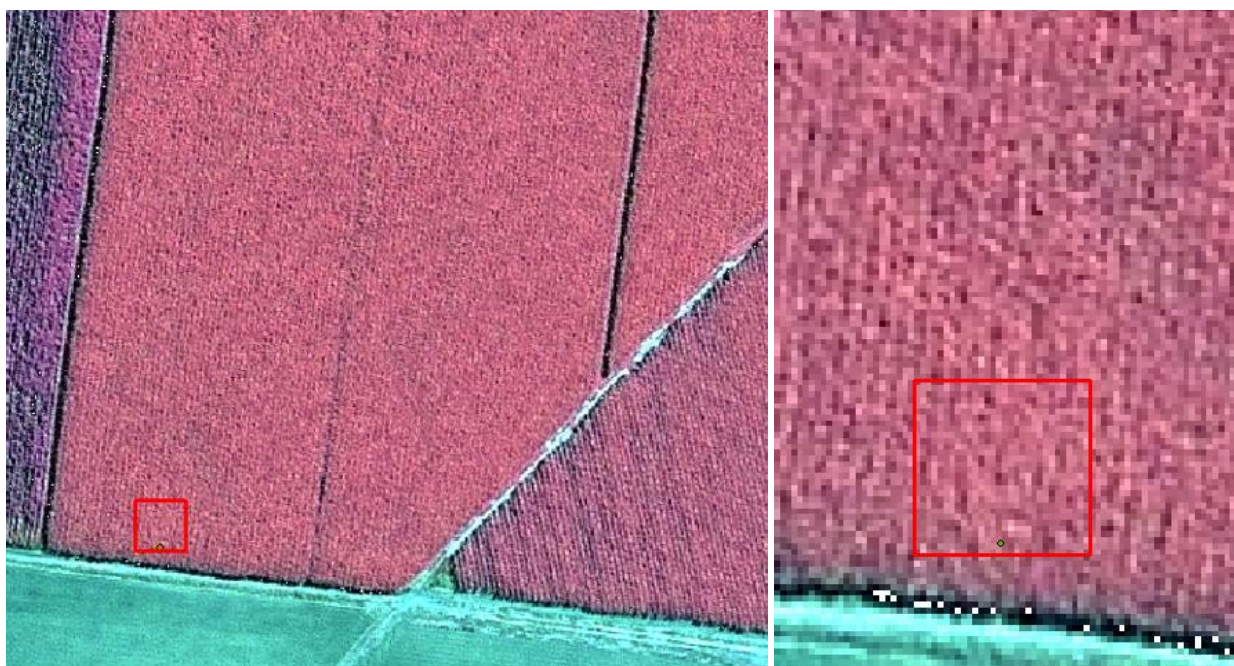
Figure 2. 30x30 pixel quadrat used to sample healthy KQ228A cane within the Mackay panchromatic image (captured 4 May 2012)
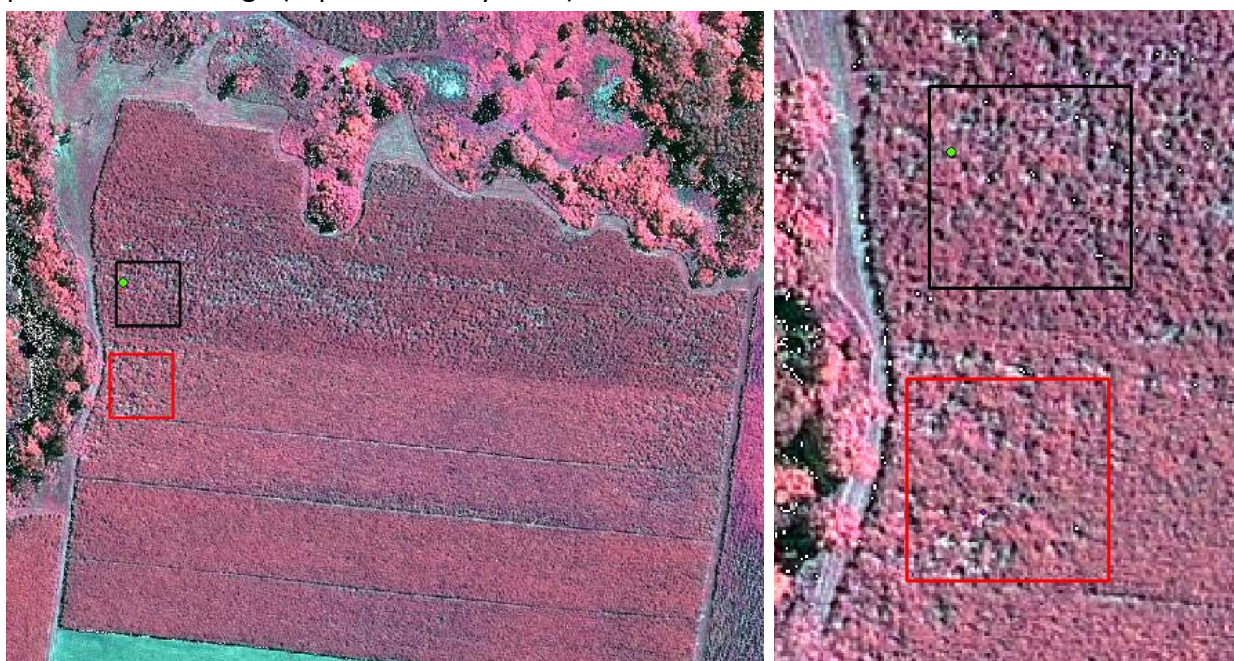

Figure 3. 80x80 pixel quadrats used to sample grub damaged Q208 (black square) and KQ228 (red square) cane within the Mackay panchromatic image (captured 4 May 2012).

However, the initial texture and spectral analysis highlighted that each cane variety exhibits significant variation in texture and spectral reflectance, therefore different pixel window sizes and quantization levels were required for image processing. Also, light grub damage in cane varieties with a smooth texture may appear similar to some healthy cane varieties with a rougher texture. Hence the processing and workload associated with per-pixel based texture analysis for grub damage

mapping purposes would become prohibitively large. In response to this finding, a new mapping approach was initiated, using GEOBIA and the eCognition Developer software, which allow not only spectral and textural information to be used, but also contextual information, object shape information and analysis at multiple spatial scales.

GEOBIA Image Classification

The eCognition Developer 9.0 software was used to develop an approach for mapping of canegrub damage by building up a rule set of conditions based on the pan-sharpened imagery. Initially, the existing GIS layer of block boundaries (4a) was used to segment the sugarcane block boundaries (Figure 4b). Subsequently, all areas with sugarcane within the block boundaries were mapped to exclude fallow and already harvested areas from further analysis (Figure 4c). Then, a fine scale segmentation at a new level was produced to divide each block into smaller homogenous objects (Figure 4d).

As canegrub damage is often manifested by reduced growth, stool tipping and exposure of bare ground, the cane occurring within an object representing 'canegrub damage' appeared less green than healthy undamaged cane. Hence, a vegetation index (Normalised Vegetation Difference Index (NDVI)) based on the red and near infrared bands (Figure 4e) was produced to automatically locate those parts of a block with the lowest 30 quantile of NDVI values. This threshold was empirically derived. The analysis was done at the block level to avoid confusion caused by different cane varieties due to their different reflectance properties.

As well as having a reduced NDVI value, the damaged areas often displayed a 'rougher' texture than healthy cane. Hence, an edge detection filter was used to identify distinct brightness edges. To reduce noise, a Gaussian smoothing filter was used to highlight areas with rough texture (Figure 4f). Subsequently, the 70 quantile (30% of highest values) of the smoothed edge layer was used to identify the 30% brightest objects, indicating areas with lots of edges, i.e. rough texture, which can be expected in areas with damaged sugarcane. This calculation was also done for each individual block to avoid confusion caused by different cane varieties. The 70 quantile (30% of highest values) of the standard deviation of the red layer objects was also used to identify those areas with the roughest texture, potentially representing damaged sugarcane. If these conditions were fulfilled, the objects were considered to be potential grub damage. Also, since breaks between individual blocks were often incorrectly classified as grub damage, they were subsequently excluded if the objects were elongated, narrow, had smooth edges and had a direction of +/- 5 degrees of the main block direction.
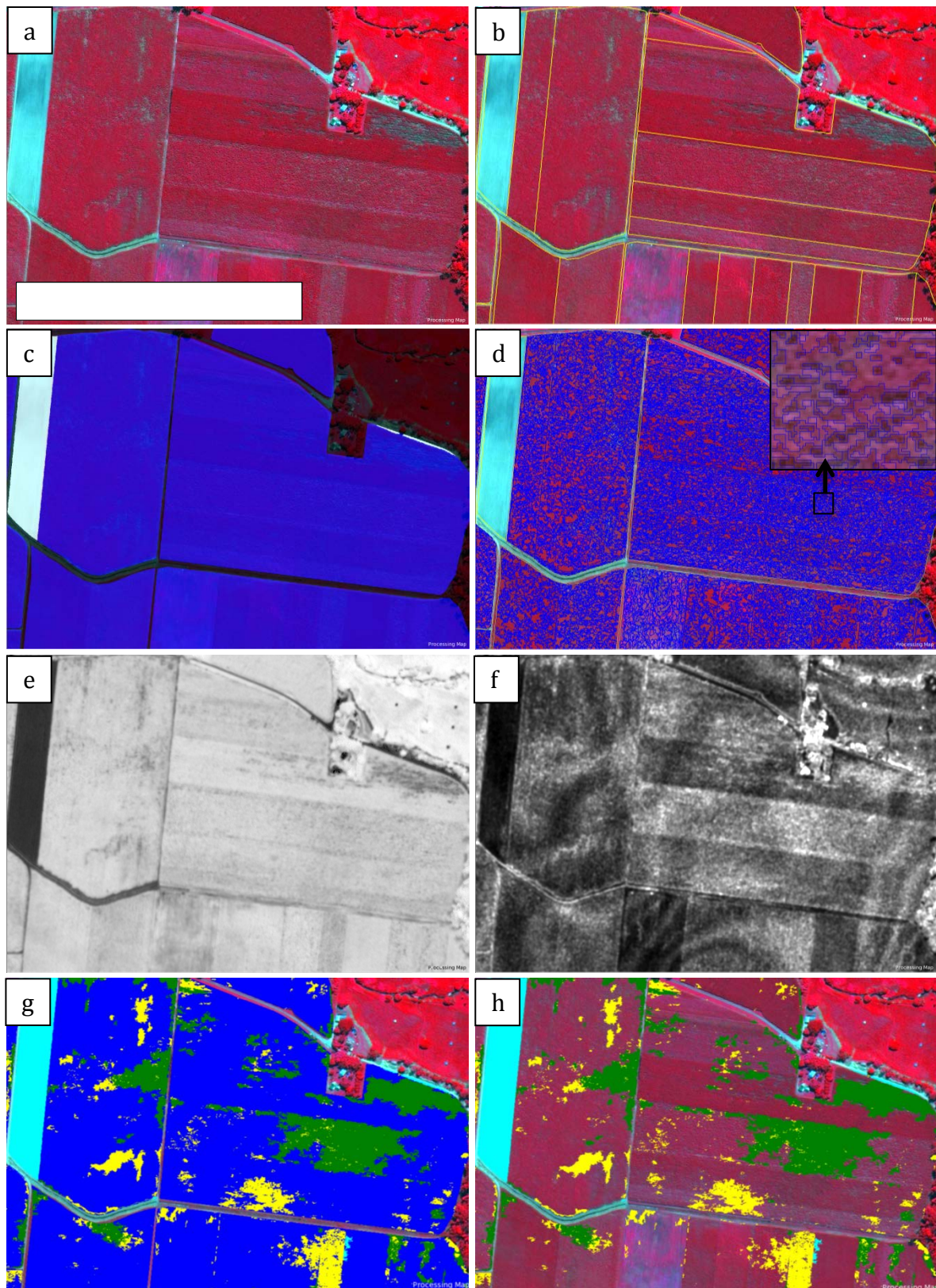
Figure 4. Processing workflow using object-based image analysis of the satellite imagery: (a) image subset in the Gordonvale area with known grub damage; (b) block boundary segmentation (yellow lines); (c) classification of fallow (white) and cane (blue) fields; (d) fine scale segmentation (blue lines); (4e) normalised difference vegetation index; (4f) texture

image; (4g) classification of likely (yellow) and less likely (cyan) grub damage; and (4h) classification of likely grub damage (yellow).

As the potential 'grub damaged' objects only represented those areas with the lowest NDVI values and roughest texture within each block at this stage in the mapping approach, it was considered important to assess the absolute NDVI and texture difference between potential grub damage objects and the remaining parts of each individual block. Hence, a number of conditions were specified in the rule set to classify potential grub damage into low, medium and high likelihood of an object representing grub damage based on how different the NDVI and texture values were in relation to the remaining parts of the block (Figure 4g). For an object to be classified as 'High' likelihood of grub damage, absolute differences above a set threshold in both NDVI and texture values were required. Further refinements to the classification was also performed, e.g. by excluding very small objects (< 50 pixels) and, if an object classified as low likelihood grub damage was completely enclosed by likely grub damage objects, the 'low likelihood' objects were reclassified 'likely' (Figure 4h).

Risk Mapping

When canegrub damage is detected, cane growers are likely to treat the entire block rather than a section of the block, and, depending on damage level and extent, growers may also decide to treat adjacent blocks. Hence, when a significant patch is a risk, the whole block or sub-block become the risk sector. With this in mind, two automated risk mapping approaches were developed based on damage mapping results. The first approach identifies the area of medium and high likelihood of grub damage within each individual sugarcane block. It then enables the user to set thresholds to define what corresponds to no risk, low risk, medium risk, high risk and/or very high risk. For example, a block with 0%; <10%; <15%; <20% and/or >20% mapped grub damage could be classified as zero; low; medium; high and/or very high risk, respectively. In some cases where known false positives were present (e.g. rat or pig damage), the thresholds can be adjusted to take that into account.

The second risk mapping approach produces a map of no risk, low risk, medium risk, high risk and very high risk based on the size of the areas with medium and high likelihood of grub damage as well as the distance to these areas. In this approach, all areas already classified as medium and high likelihood of grub damage are reclassified as "very high risk", as these areas are very likely to be affected in the following growing season. The following values represent an example only, which corresponds to the map provided in the results section (Figure 7). If the area of very high risk is > 200 m^2, then concentric buffer zones were created surrounding the very high risk areas, with zones being progressively 25 m wide of high risk, 15 m wide of medium risk, and 10 m wide of low risk. For very high risk objects between 100 and 200 m^2, concentric buffers of 15 m, 10 m and 10 m of high, medium and low risk, respectively, were produced. Finally, for very high risk objects between 25 and 100 m^2, buffers of 5 m, 10 m and 10 m of high, medium and low risk, respectively, were produced. The remaining small "very high risk areas" (<25 m^2) were classified as low risk. This approach was designed not to take into account breaks between the individual blocks, meaning that buffers

representing various risk levels would be produced for neighbouring blocks even if grub damage did not occur within that block. Thresholds in terms of object size and width of buffers can be adjusted to meet the needs of different regions or based on local knowledge.

Results Summary/Milestone 9
- ### *Images analysed and data correlated with ground observations*

The final set of GeoEye-1 satellite images were collected in April (Bundaberg, Isis), May (Mackay, Burdekin) and June (Mulgrave) 2014. These images were all radiometrically and geometrically corrected and orthorectified, pan-sharpened and geometrically aligned with the shapefiles of the sugarcane block boundaries supplied by the Productivity Services/mills. Subsequently, the images were classified into four classes (zero; low; medium and high likelihood of grub damage) using the latest version of the developed rule set in the eCognition software. Field data were collected for all the study sites including information on the presence and absence of grub damage and other disorders. These data were used to assess grub damage mapping accuracy.

Mackay 2014 (Fig. 5)
Field data of grub damage collected independently of the image capture:
- 38 locations with grub damage correctly mapped (86.4%).
- 6 locations with grub damage were over-looked (13.6%), but 2 of the 6 locations were within 30 m of mapped grub damage in the same block.

Field data of grub damage collected after image capture based on suspected grub damage:
- 107 locations with grub damage correctly mapped (87.0%).
- 16 locations with grub damage were over-looked (13.0%), but 14 of the 16 locations were within 30 m of mapped grub damage in the same block.

Field data of sites without grub damage collected after image capture based on suspected grub damage:
- 4 locations correctly mapped without grub damage (22.2%).
- 14 locations incorrectly mapped as grub damage in an area with no grub damage detected in the field (77.8%). Ten of these 14 sites showed signs of sprawling.
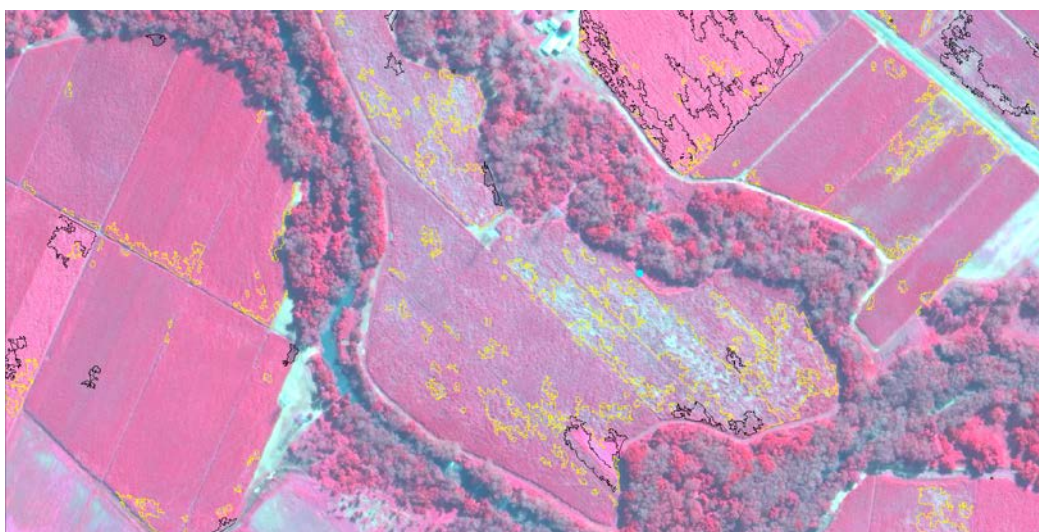
Figure 5. Subset of the Mackay area showing mapped grub damage in May 2014. Yellow and black outlines indicate high and low likelihood of grub damage, respectively.

Table 2. Grub counting compared with map detection for the Mackay area in May 2014.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
2	Not detected
45	High likelihood of grub damage detected within polygon
16	High likelihood of grub damage detected within 3 m
61	High likelihood of grub damage detected within 4.5 m
18	High likelihood of grub damage detected within polygon
55	High likelihood of grub damage detected within polygon
21	High likelihood of grub damage detected within polygon
20	High likelihood of grub damage detected within polygon
6	High likelihood of grub damage detected within polygon
29	High likelihood of grub damage detected within polygon
10	High likelihood of grub damage detected within polygon
13	High likelihood of grub damage detected within polygon
13	High likelihood of grub damage detected within polygon
33	High likelihood of grub damage detected within polygon
12	High likelihood of grub damage detected within polygon
10	High likelihood of grub damage detected within polygon
10	High likelihood of grub damage detected within polygon
27	High likelihood of grub damage detected within polygon

Mapped grub damage was compared with grub counting within 20 m x 20 m blocks (Table 2). All areas were mapped as "high likelihood of grub damage", except for one site with a grub density of 2 in 20 x 20 m block, which was not detected.

Mulgrave 2014

Field data of grub damage collected independently of the image capture:

- 32 out of 42 locations with grub damage were correctly mapped (76.2%), while 10 locations (23.8%) with light grub damage were over-looked
- 82 out of 135 locations with no grub damage were correctly mapped (60.7%), while 53 locations (39.3%) were incorrectly mapped as grub damage. Seventeen of these sites showed signs of wind damage and 11 of these sites showed signs of lodging. Sprawling, water damage, pig damage, YCS, stunted growth and weeds accounted for the remaining 25 sites.

Field data of grub damage collected after image capture based on suspected grub damage:

- 47 out of 48 locations with grub damage correctly mapped (97.9%).
- 15 of 143 locations without grub damage (10.5%) were correctly identified. A total of 89 locations mapped as grub damage appeared with wind damage caused by Cyclone Ita, which went through the area in the first half of April 2014. The remaining false positives were mainly caused by sprawling, lodging and gappy sugarcane canopies (Table 3).

Table 3. Disorders incorrectly interpreted as grub damage (first 3 data columns) and disorders correctly interpreted as no grub damage (4th data column) for Mulgrave, June 2014:

Types of damage identified in the field	Mapped as Low Likelihood	Mapped as Medium Likelihood	Mapped as High Likelihood	Mapped as No Grub Damage
Gaps		1	6	
Wind	23	19	47	10
Stunted	1	1	2	2
Pig / Rat			5	2
Sprawling	1		2	
Lodging	5	2	8	1
Water	3		1	
Vine			1	

Mapped grub damage was compared with grub counting within 20 m x 20 m blocks (Table 4). The number of grubs detected within each block was not correlated with the mapped likelihood of grub damage. It is probably the case that grubs had already finished feeding and moved deeper in the soil. This usually occurs earlier in Far North Queensland compared to the Central district due to higher temperature and rainfall levels.

Table 4. Grub counting compared with map detection for the Mulgrave area 2014.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
1	Grub damage detected within 3 m
14	Covered by clouds
15	Moderate likelihood of grub damage detected within polygon
7	High likelihood of grub damage detected within polygon
3	Low likelihood of grub damage detected within polygon
1	Covered by cloud shadow
15	Covered by cloud shadow
15	High likelihood of grub damage detected within polygon
9	High likelihood of grub damage detected within polygon
9	Low likelihood of grub damage detected within polygon
1	Low likelihood of grub damage detected within polygon
4	High likelihood of grub damage detected within polygon
1	Outside the imaged area
3	Outside the imaged area
2	High likelihood of grub damage detected within polygon
4	Moderate likelihood of grub damage detected within polygon

Burdekin 2014

Very little grub damage was found in the Burdekin most likely due to the widespread application of insecticides in that district. However, significant lodging of the Burdekin crop in 2014 led to overestimation of grub damage. Hence, the current mapping approach may not be ideal for the Burdekin region where crop sprawling and lodging are common. In 2013, Burdekin site images were collected in March, May and June. The March image showed far less sprawling and lodging compared to the May and June images, leading to a more realistic damage estimation compared to the May and June images. Images may therefore be captured before lodging occurs in the Burdekin. In the developed ruleset, thresholds for image texture and NDVI values can be adjusted to reduce damage overestimation. However, this may also reduce the chances of identifying grub damage due to its high resemblance to sprawling.

Bundaberg 2014

Field data of grub damage collected after image capture based on suspected grub damage:
- 36 locations with grub damage correctly mapped (97.3%).
- 1 location with grub damage was over-looked (2.7%).

Field data of sites without grub damage collected after image capture based on suspected grub damage:

- 5 locations correctly mapped without grub damage (45.4%)
- 6 locations incorrectly mapped as grub damage in an area with no grub damage detected in the field (54.6%).

Isis 2014

Field data of grub damage collected after image capture based on suspected grub damage:
- 77 locations with grub damage correctly mapped (81.9%).
- 17 locations with grub damage were over-looked (18.1%).

Field data of sites without grub damage collected after image capture based on suspected grub damage:
- 34 locations correctly mapped without grub damage (75.6%)
- 11 locations incorrectly mapped as grub damage in an area with no grub damage detected in the field (24.4%).

Based on these results, it is clear that some sites achieved higher mapping accuracies than others. Although the overall damage detection rate was high for all the study sites, the frequency of false detections varied between sites. This variation was also subject to the degree of disturbance present. For example, the occurrence of cyclone Ita over Mulgrave in April 2014 resulted in a high percentage of false positives. Hence, the mapping accuracies related to false positives (mapping of non-grub damage areas as grub damage) are likely to relate directly to the level of the non-grub damage confounding factors present. Thresholds in the rule set may therefore require adjustment to minimise false positives and at the same time maintain a high damage detection accuracy.

- *2012/13 images re-analysed in light of new data*

Based on the latest version of the eCognition rule set developed, the images from 2012 and 2013 were re-processed and re-analysed. To demonstrate the difference in the mapping results, the accuracies reported in Milestone 7 Report were compared to the latest results.

Table 5-1. Accuracy assessment of imaged grub damage at the Mulgrave site, 26 May 2013 (from Milestone Report 7).

	Light Grub Damage	Moderate Grub Damage	Heavy Grub Damage
Classified correctly	61	26	8
Not classified	20	11	2
% correctly classified	75.3%	70.3%	80%

Table 5-2. Accuracy assessment of imaged grub damage at the Mulgrave site, 26 May 2013 using the latest eCognition rule set. Information on the classification of "no grub damage" are in Table 5-3.

	Light Grub Damage	Moderate Grub Damage	Heavy Grub Damage
Classified correctly	80	37	10
Not classified	1	0	0
% correctly classified	98.8%	100%	100%

Table 5-3. Disorders incorrectly interpreted as grub damage (first 3 data columns) and disorders correctly interpreted as no grub damage (4th data column) for Mulgrave, May 2013 – estimated using the latest version of the eCognition rule set.

Actual damage identified in the field	Mapped as Low Likelihood	Mapped as Medium Likelihood	Mapped as High Likelihood	Mapped as No Grub Damage
Water		3	4	
Weed		9	5	3
Sprawling		13	12	2
Indian file		3	3	2
Gaps		5	7	1
Rat / Pig		2	4	
Old damage			2	
Lodging		7	6	2
Stunted	1	6	13	1
Herbicide		1		
Funnel ants		1		

Table 6-1. Accuracy assessment of Mulgrave site, 26 May 2013 based on field data collected independently of image data (from Milestone Report 7).

	Light Grub Damage	Moderate Grub Damage	Heavy Grub Damage
Classified correctly	7	10	3
Not classified	16	10	1
% correctly classified	30.4%	50.0%	75%

Table 6-2. Accuracy assessment of Mulgrave site, 26 May 2013 based on field data independent of image data using the latest eCognition rule set.

	Light Grub Damage	Moderate Grub Damage	Heavy Grub Damage
Classified correctly	16	17	3
Not classified	7	3	1
% correctly classified	69.6%	85.0%	75%

For the Mulgrave study site, the detection rate of light, moderate and heavy grub damage increased significantly (Tables 5-1, 5-2, 6-1 and 6-2) using the latest version of the eCognition rule set. However, areas with other disturbances, especially heavy sprawling and stunted sugarcane resulted in mapping errors of commission (Table 5-3). Many of these confounding factors have very similar image spectral and textural characteristics to grub damage symptoms. Hence, reducing the number of false positives will also affect the mapping accuracies of grub damage. The only likely way to further improve the mapping accuracy (i.e. to reduce the likelihood of interpreting non-grub damage as grub damage) would be to apply manual editing after the image had been processed via ground truthing. However, noting non-grub disorders is also important to further assess the overall yield condition.

Table 7-1. Accuracy assessment of imaged grub damage at the Mackay site, 26 May 2013 (from Milestone Report 7).

	Grub Damage	No Grub Damage
Classified correctly	35	8
Not classified	17	10
% correctly classified	67.3%	44.4%

Table 7-2. Accuracy assessment of imaged grub damage at the Mackay site, May 2013 using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	49	4
Not classified	3	14
% correctly classified	94.2%	22.2%

Table 8-1. Accuracy assessment of Mackay site, 26 May 2013 based on field data independent of image data (from Milestone Report 7).

	Grub Damage	No Grub Damage
Classified correctly	16	0
Not classified	15	0
% correctly classified	51.6%	0

Table 8-2. Accuracy assessment of Mackay site, May 2013 based on field data independent of image data using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	28	0
Not classified	3	0
% correctly classified	90.3%	0

A significant increase in the detection rate of field identified grub damage did also occur for the Mackay study site when latest version of the eCognition rule set was used. For field data collected based on image-selected sites, the mapping accuracy increased from 67% to 94% (Tables 7-1 and 7-2). For field data collected independently of the image data, the mapping accuracy increased from 52% to 90% (Tables 8-1 and 8-2). However, as can be seen in Tables 7-1 and 7-2, there was an increase in the number of false positives (where sprawling was the main disorder). This resulted in a decrease in the mapping accuracy of non-grub damage areas from 44% to 22%. While both of these mapping accuracies of non-grub damage are quite low, it should be highlighted that all location points included in tables 7-1 and 7-2 were selected because they represented image-identified disturbances which were incorrectly considered to be grub damage. If areas with healthy undisturbed sugarcane had been included, these mapping accuracy of non-grub damage areas would increase significantly.

Table 9-1. Accuracy assessment of imaged grub damage at the Burdekin site, 26 May 2013 (from Milestone Report 7).

	Grub Damage	No Grub Damage
Classified correctly	15	14
Not classified	14	22
% correctly classified	51.7%	38.9%

Table 9-2. Accuracy assessment of imaged grub damage at the Burdekin site, May 2013 using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	29	25
Not classified	0	11
% correctly classified	100%	30.6%

Table 10-1. Accuracy assessment of Burdekin site, 26 May 2013 based on field data independent of image data (from Milestone Report 7).

	Grub Damage	No Grub Damage
Classified correctly	3	0
Not classified	2	0
% correctly classified	60.0%	0

Table 10-2. Accuracy assessment of Burdekin site, May 2013 based on field data independent of image data using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	5	0
Not classified	1	0
% correctly classified	83.3%	0

For the Burdekin study site, the detection rate of grub damage did also increase (Tables 9-1, 9-2, 10-1 and 10-2) when the latest eCognition rule set was used. Both Tables 9-1 and 9-2 show that areas with "grub-like" symptoms were likely to be incorrectly mapped as grub damage. However, when the 27/3/13 image was used instead of the 26/5/13 image, a higher mapping accuracy was achieved for non-grub damage sites. This was because lodging and sprawling was far less prevalent earlier in the growing season. This did however reduce the mapping accuracy of grub damage from 100% to 73.3% (Table 11-2), as symptoms such as leaf colour and texture change due to stool tipping were less obvious at that stage of the growing season. Because of the large number of false positives caused by lodging and sprawling in May, it is recommended to source imagery in late March/early April before sprawling and lodging become dominant in the Burdekin region.

Table 11-1. Accuracy assessment of Burdekin site, 27 March 2013 based on field data independent of image data using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	5	0
Not classified	1	0
% correctly classified	83.3%	0

Table 11-2. Accuracy assessment of imaged grub damage at the Burdekin site, 27 March 2013 using the latest eCognition rule set.

	Grub Damage	No Grub Damage
Classified correctly	22	24
Not classified	8	13
% correctly classified	73.3%	64.9%

Childers, 2013: 12 out of 14 locations (85.71%) identified with grub damage in the field were also mapped as likely grub damage. The remaining two locations not mapped with grub damage were categorised as light grub damage.

Bundaberg, 2013: 17 out of 20 locations (85.00%) identified with grub damage in the field were also mapped as likely grub damage. The remaining three locations not mapped with grub damage were categorised as light grub damage.

Mackay, 2012: 76 out of 77 locations (98.7%) identified with grub damage in the field were also mapped as likely grub damage. Five of the 76 mapped locations appeared with a low likelihood of grub damage. These five sites were all identified in the field with symptoms of light grub damage.

Burdekin, 2012: No field validation data were available for the Burdekin site for 2012.

Mulgrave, 2012: 112 out of 130 locations (86.2%) identified with grub damage in the field were also mapped as likely grub damage. One of the 112 mapped locations appeared with a low likelihood of grub damage. This site was identified in the field with symptoms of light grub damage. Sixteen of the 18 locations not mapped as grub damage (false negatives) were identified in the field as light grub damage.

Childers, 2012: 30 out of 37 locations (81.08%) identified with grub damage in the field were also mapped as likely grub damage. The remaining seven locations not mapped with grub damage were categorised as light grub damage in four cases, moderate grub damage in one case and heavy grub damage in two cases.

Bundaberg, 2012: 37 out of 45 locations (82.22%) identified with grub damage in the field were also mapped as likely grub damage. The remaining eight locations not mapped with grub damage were categorised as light grub damage in six cases, moderate grub damage in one case and heavy grub damage in one case.

- *Infested patches quantified with regard to soil types and vegetation*

Grub infestation and soil type

Field identified grub damage in 2014 in Mulgrave was regressed against a soil type layer provided by the mill. These two layers were intersected in ArcGIS to assess the number of occurrences of grub damage within each soil type. There was no clear trend in the soil type on which different grub damage levels were found (Tables 12-14), where 36.1% of the total damage was found on well drained soils compared to 23.7% and 39.2% occurring on poorly drained and red soils, respectively (Table 15). Based on these findings and the findings from 2013, soil type may not be a reliable factor to assist in damage prediction. It needs to be stated that insecticide usage disrupts the correlation between grub damage and soil types.

Table 12. Light grub damage identified in the field in 2014 on different soil types.

Soil types with light grub damage	Number of occurrences	%
Poorly drained clay	10	13.2
Well drained granitic	20	26.3
Well drained clay	3	3.9
Well-drained recent alluvium	2	2.6
Poorly drained granitic	9	11.8
Red Earth	8	10.5
Made Land	1	1.3
Red/Brown Schists and Volcanics	23	30.3

Table 13. Moderate grub damage identified in the field in 2014 on different soil types.

Soil types with moderate grub damage	Number of occurrences	%
Poorly drained granitic	3	20
Red/Brown Schists and Volcanics	1	6.7
Red Earth	2	13.3
Poorly drained clay	1	6.7
Well drained recent alluvium	1	6.7
Well drained clay	1	6.7
Well drained granitic	6	40

Table 14. Heavy grub damage identified in the field in 2014 on different soil types.

Soil types with heavy grub damage	Number of occurrences	%
Red/Brown Schists and Volcanics	4	66.7
Well drained granitic	2	33.3

Table 15. Any level of grub damage identified in the field in 2014 on different soil types.

Soil types with any level of grub damage	Number of occurrences	%
Poorly drained clay	11	11.3
Well drained granitic	28	28.9
Well drained clay	4	4.1
Well-drained recent alluvium	3	3.1
Poorly drained granitic	12	12.4
Red Earth	10	10.3
Made Land	1	1.0
Red/Brown Schists and Volcanics	28	28.9

Grub infestation and vegetation features

Vegetation features and their spatial arrangement in the landscape were assessed in relation to grub damage distribution in Mulgrave by Peter Zellner (CIRAD, France - Appendix 1). The overall findings suggest that trees bordering cane fields play a major role in the occurrence of canegrub damage. However, it is likely that spatial arrangement of vegetation is one of many variables affecting damage patterns and that the influence of vegetation may vary in relation to other factors (insecticide treatment, soil type, soil moisture levels, cane variety etc.). Hence, there is currently no sufficient evidence to include vegetation as a deterministic variable in the eCognition rule set for mapping the of grub damage likelihood.

- **Grub Counting**

Based on the latest version of the eCognition rule set, a mixed range of grub densities occurred within areas mapped as moderate or high damage based on the Mackay 20 m x 20

m grub counts in 2013. No damage was mapped in two cases where 11 and 22 grubs were identified in the field within a 20 m x 20 m block. While in one case grub damage had been mapped but no grubs were found in the field. In all other cases, grub damage was mapped in those blocks with grubs identified. Grub counts for the Mackay area in 2012 did also correspond well with the mapping results in most cases (Table 17). The grub counts for the Burdekin correlated well with the low, moderate and high likelihood mapping categories, with fewer grubs identified in the field for areas mapped as low likelihood of grub damage and more grubs identified for high likelihood sites (Tables 18 and 19). Areas with sprawling were in some cases mapped as high likelihood of grub damage for Mulgrave and Burdekin sites (Tables 18-20). Grub counts for Mulgrave were not available for 2013. Also, no grub counts for the Childers and Bundaberg areas were available for 2012 and 2013.

Table 16. Grub counts compared with map detection using the June 2013 image - Central district.

Grub counting within 20 m x 20 m block	Map detection
2	Moderate likelihood of grub damage detected within polygon
11	No grub damage detected
7	High likelihood of grub damage detected within 3 m
22	No grub damage detected
34	High likelihood of grub damage detected within 15 m
16	High likelihood of grub damage detected within polygon
47	High likelihood of grub damage detected within polygon
0	No grub damage detected
10	High likelihood of grub damage detected within polygon
9	High likelihood of grub damage detected within polygon
0	High likelihood of grub damage detected within polygon
12	High likelihood of grub damage detected within polygon
31	High likelihood of grub damage detected within polygon
22	High likelihood of grub damage detected within polygon
9	High likelihood of grub damage detected within polygon
27	Moderate likelihood of grub damage detected within polygon
14	High likelihood of grub damage detected within polygon

Table 17. Grub counting compared with map detection for the Central district area, 2012.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
21	Moderate likelihood of grub damage covering whole polygon
20	High likelihood of grub damage covering whole polygon
0	Low likelihood of grub damage detected within polygon
4	No grub damage detected within polygon
15	No grub damage detected within polygon (as other parts this field with unhealthy looking cane were mapped as high likelihood of grub damage)

43	Moderate likelihood of grub damage covering whole polygon
71	Moderate likelihood of grub damage covering whole polygon
33	Moderate likelihood of grub damage detected within polygon
41	High likelihood of grub damage covering whole polygon
43	High likelihood of grub damage covering whole polygon
26	High likelihood of grub damage detected within polygon
28	High likelihood of grub damage covering most of polygon
27	High likelihood of grub damage covering whole polygon
23	High likelihood of grub damage covering whole polygon
5	High likelihood of grub damage covering small part of polygon
14	High likelihood of grub damage detected within polygon
0	High likelihood of grub damage detected within polygon
2	No grub damage detected
6	No grub damage detected
17	Areas of low and high likelihood of grub damage detected within polygon
50	High likelihood of grub damage covering small part of polygon within the 20 x 20 m section, however, the majority of the block was mapped as high likelihood of grub damage as damage in the remaining part of the block (outside the 20 x 20 m section) was much higher than the area within the polygon.

Table 18. Grub counting compared with map detection for the Burdekin area, 2013.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
12	Low likelihood of grub damage detected within polygon
35	High likelihood of grub damage covering whole polygon
9	High likelihood of grub damage detected within polygon (possibly sprawling)

Table 19. Grub counting compared with map detection for the Burdekin area, 2012.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
3	No grub damage detected within polygon
25	High likelihood of grub damage covering whole polygon
7	Low likelihood of grub damage detected within polygon
5	No grub damage detected within polygon
8	Low likelihood of grub damage detected within polygon
30	Moderate likelihood of grub damage covering most of the polygon
33	High likelihood of grub damage detected within polygon
0	High likelihood of grub damage detected within polygon (because of sprawling)

Table 20. Grub counting compared with map detection for the Mulgrave area, 2012.

Grub counting within 20 m x 20 m block (grubs/20 stools)	Map detection
33	Low likelihood of grub damage detected within polygon
5	Moderate likelihood of grub damage detected within polygon
0	High likelihood of grub damage detected within polygon (possibly sprawling)
3	Moderate likelihood of grub damage detected within polygon
6	Moderate likelihood of grub damage detected within polygon
7	No grub damage detected within polygon
2	No grub damage detected within polygon
3	No grub damage detected within polygon
49	Outside of study area

- ***Detection algorithms finalised and error rate quantified***

The eCognition detection algorithm (rule set) has been finalised and was found to be suitable for all study sites except the Burdekin where extensive sprawling was often mapped as grub damage. The latest version of the algorithm may still be further improved if additional ancillary information can be incorporated (i.e. information on treated and untreated blocks). This could be particularly useful for the Burdekin site, where most blocks are treated and would effectively minimize the chances of grub damage being incorrectly mapped in treated areas that may exhibit grub damage-like appearance due to any other disorder. The finalised algorithm relies on high spatial resolution pre-processed satellite image data (1 m pixels) with blue, green, red and near infrared bands as well as a polygon shapefile of the sugarcane block boundary outlines. It is essential that the imagery be captured towards the end of the growing season (April – June) when grub damage is most prevalent in the form of stool tipping and changes of leaf colour. Lower spatial resolution imagery (such as SPOT-5 image data with 10 m pixels) was also tested but found unsuitable due to the lack of spatial details. This type of image data will be most suitable for yield predictions as reported by Robson et al. (2012). The best chance of grub damage detection with SPOT-5 type imagery would be to look for grub damage in low yield areas. However, this is still limited to areas of at least 100 m^2, whereas high spatial resolution image data can detect smaller scale disturbances.

The detection algorithm allows the user to adjust the thresholds for changes in greenness and texture caused by grub damage to attune the algorithm to different areas. For example different thresholds were required for the Burdekin to reduce the number of false positives due to extensive lodging and sprawling. Based on the results reported above, most grub damage will be detected but certain other disorders may still be incorrectly mapped as grub damage. However, a degree of ground truthing will still be required to confirm the cause of disorder and to improve the model progressively. It also appears that the use of a time-series

of image data (multiple images captured over several years) will not necessarily improve the damage detection rate in any particular year, although will demonstrate the degree of expansion (or decrease) of the area damaged over time.

The detection algorithm also includes two types of risk predictions. The first risk prediction applies a simple threshold for each of five risk categories: no risk, low risk, moderate risk, high risk and very high risk. These thresholds are based on the percentage of area mapped as grub damage per sugarcane block. An example is provided below showing no risk (< 5% mapped grub damage), low risk (< 10% mapped grub damage), moderate risk (<15% mapped grub damage), high risk (<20% mapped grub damage) and very high risk (>20% mapped grub damage) (Figure 6). The risk thresholds can be adjusted by the user to take into account false positives. This approach may also be used to assess crop condition for example after a severe weather condition (i.e. following a cyclone event). Another developed risk prediction algorithm assigns an area as no risk, low risk, moderate risk, high risk and very high risk based on its distance to areas mapped with medium and high likelihood of grub damage. The distance thresholds can be adjusted by the user to suit different regions. An example is provided in Figure 7.
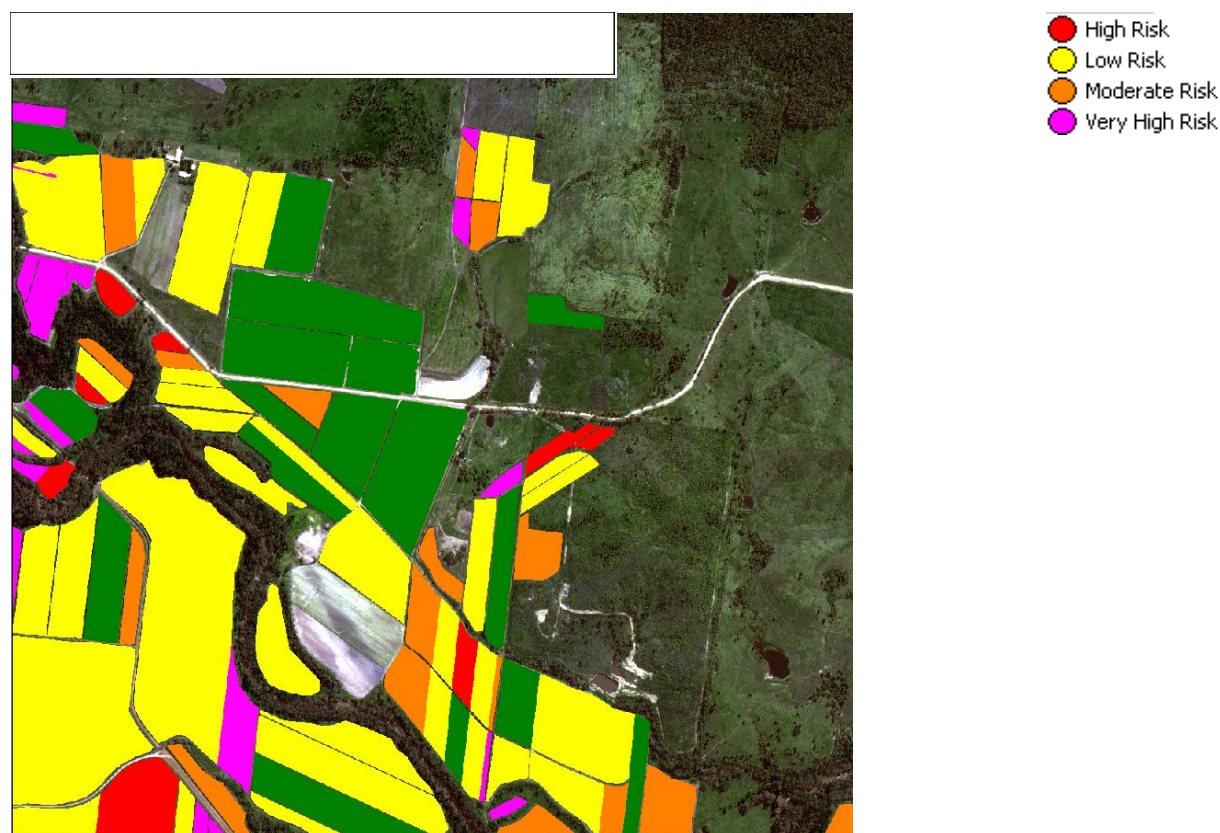

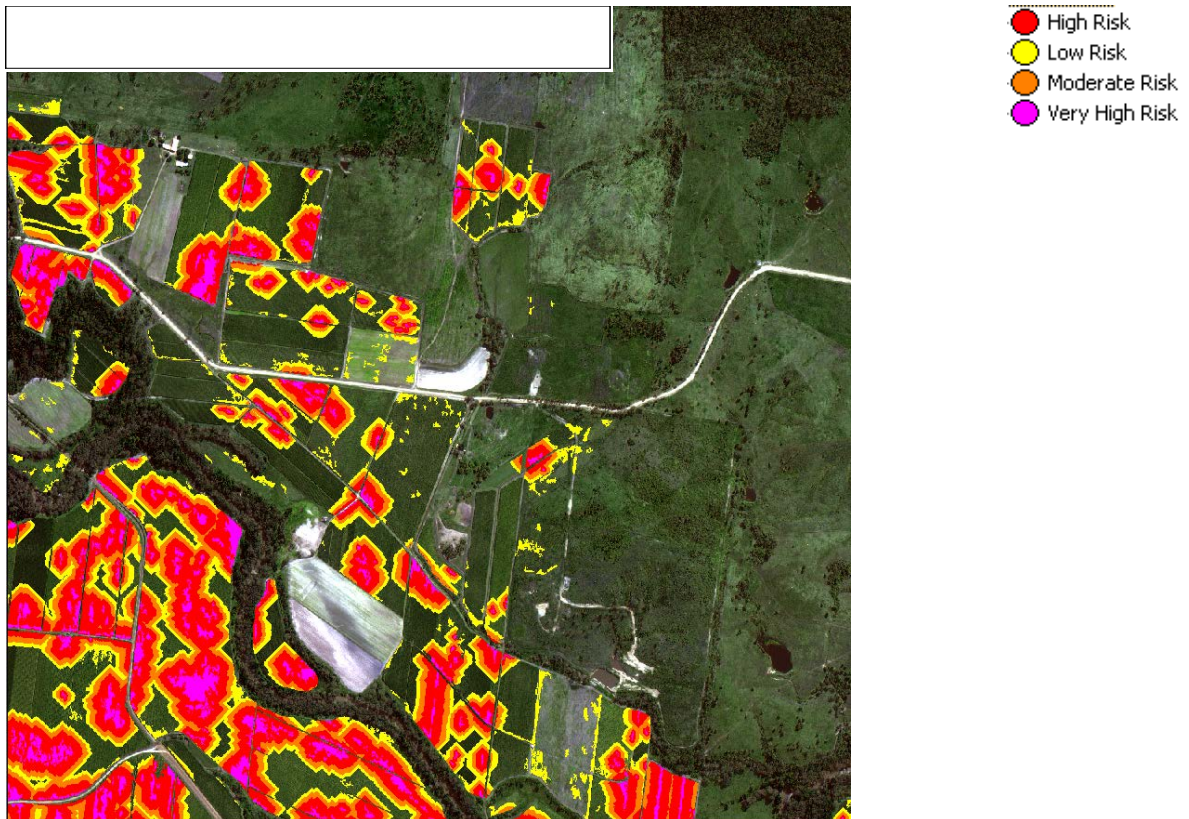Figure 6. Risk map showing blocks with different extent of grub damage.

Figure 7. Risk map showing different levels of risk based on distance to mapped grub damage.

Skills obtained/ products developed

Damage prediction/Risk maps

Using the GEOBIA and the "eCognition" software, as well as ground truthing, risk maps could be produced showing existing and potential grub damage in each region. Example on damage predicted using the satellite image is given in Figures 8 and 9.

Figure 8. Points with confirmed damage from greyback canegrub near Mackay, 2013, located independently of (red circles) and dependent on (blue circles) the image analysis
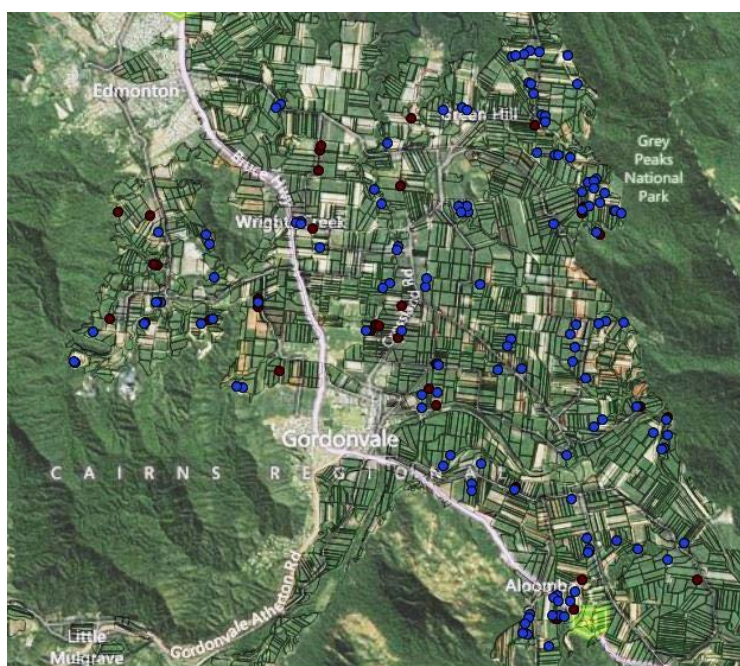

Figure 9. Points with confirmed canegrub damage in Mulgrave, 2013, located independently of (red circles) and dependent on (blue circles) the image analysis

Initial risk layers were produced based on field identified grub damage and also on the assumption that the whole block (within which grub damage is identified) is at risk as well as neighbouring blocks. An example is provided in Figures 10 a &b below showing initial risk maps produced in 2013.

Figure 10 (a). Grub damage identified in the field in the Central District (2013).

Figure 10 (b). Blocks deemed at risk of grub damage in the Central District based on field inspection results in 2013.

Following a survey conducted during May-June 2014, growers and Productivity Service members in Mulgrave, Burdekin and Mackay preferred a map with the actual damage shapes/polygons as generated using GEOBIA after ground-truthing (which is option 10 in the questionnaire attached as Appendix 2). However, option 12 (gradient colouring/not incriminating to a particular grower) was preferred in the Herbert. This same option was also acknowledged by Mulgrave participants as a good option along with option 13. Questionnaire results are presented in detail in Appendices 3 & 4. A KML

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file showing exact damaged shapes on Google Earth is attached to this report (GEOBIA exact polygons. KML)

Model developed / Detection algorithms refined

The most recent improvement of the eCognition Rule Set for classifying grub damage is presented in Appendix 5.

Summary and general discussion of project results

Canegrub Mapping

There are two standard types of accuracies, i.e. user's accuracy and producer's accuracy, which relate to error of commission (false positives) and error of omission (false negatives), respectively. Producer's accuracy refers to the probability that a certain land-cover of an area (e.g. grub damage) is classified as such. Producer's accuracy relates to error of omission (false negative), i.e. producer's accuracy = 100 – omission error. User's accuracy refers to the probability that a pixel labelled as a certain land-cover class (e.g. grub damage) in the map is correctly this class. User's accuracy is a measure of error of commission (false positives), i.e. user's accuracy = 100 – commission error.

Two types of field data were collected each year for the five study sites: (1) canegrub damage location identified independently of the image data; and (2) type of damage at locations visually identified from the image data as potential canegrub damage. As the independent sample points only included grub damage observations, it was only possible to calculate the producer's accuracy and error of omission (false negatives) based on these field data. As the sample points visually selected from the imagery included both grub damage observations and observations of non-grub damage, it was possible to calculate both the user's and producer's accuracies, i.e. both errors of commission (false positives) and omission (false negatives) from these field data. However, the measure of user's accuracy and error of commission (false positives) was highly biased and not a fair measure of error of commission, because those sample points that were visually selected from the imagery were selected because they looked like some kind of damage. Therefore, healthy-looking cane was not included, which means the user's accuracy is likely to be higher in reality and the error of commission (false positives) is likely to be lower in reality. This summary of results therefore reports on producer's accuracy and error of omission (false negatives) only, via combining field observations collected independently of the image data with field observations made at locations selected based on image data. Combining these two sources of field data was deemed feasible because the eCognition rule set was developed to accommodate most "appearances" of grub damage in the images rather than using the individual sites from field observations for classification training of the model.

For all five study sites, high producer's accuracies were achieved, indicating that most areas that were identified with grub damage in the field were also mapped as having grub damage (Tables 21-25). Only little variation in the producer's accuracies occurred from year to year. The algorithm developed

performed well for the Mackay and Mulgrave districts, whereas the results for the Burdekin district were less successful because of the significant amount of sprawling and the general absence of grub damage. The producer's mapping accuracies of the Bundaberg and Childers sites were > 80% in 2012, 2013 and 2014.

Despite the insufficient validation data available for assessing user's accuracies, the number of false positives identified at some of the sites varied from year to year. For example, the damage caused by cyclone Ita in Mulgrave in 2014 increased the number of false positives, as wind damage in many cases had similar characteristics to canegrub damage symptoms. Also, sprawling in the Burdekin area, in particular, caused significant overestimation of potential grub damage. Other types of damage, e.g. weed damage, pig damage and rat damage, did also result in overestimation of grub damage. Therefore, a conclusion of this research is that most existing grub damage is successfully mapped, but other disorders are in many cases included as potential grub damage using the developed mapping approach. Although this is undesirable from a grub damage mapping viewpoint, growers may be able to take advantage of this additional information as an indication of general crop health.

Table 21. Measure of producer's accuracy and error of omission (false negatives) for mapping canegrub damage in 2012, 2013 and 2014 for the Mackay site, including all field data.

Actual damage	2012	2013	2014
Classified correctly	76	77	145
Not classified	1	6	22
% correctly classified	98.7%	92.8%	86.8%
% false negatives	1.3%	7.2%	13.2%

Table 22. Measure of producer's accuracy and error of omission (false negatives) for mapping canegrub damage in 2012, 2013 and 2014 for the Mulgrave site, including all field data.

Actual damage	2012	2013	2014
Classified correctly	112	163	79
Not classified	18	12	11
% correctly classified	86.2%	93.1%	87.8%
% false negatives	13.8%	6.9%	12.2%

Table 23. Measure of producer's accuracy and error of omission (false negatives) for mapping canegrub damage in 2012, 2013 and 2014 for the Burdekin site, including all field data.

Actual damage	2012	2013	2014
Classified correctly	Not available	27	1
Not classified	Not available	9	0
% correctly classified	Not available	75.0%	Not enough data
% false negatives	Not available	25.0%	Not enough data

Table 24 Measure of producer's accuracy and error of omission (false negatives) for mapping canegrub damage in 2012, 2013 and 2014 for the Childers site, including all field data.

Actual damage	2012	2013	2014
Classified correctly	30	12	111
Not classified	7	2	17
% correctly classified	81.08%	85.71%	88.1%
% false negatives	18.92%	14.29%	11.9%

Table 25 Measure of producer's accuracy and error of omission (false negatives) for mapping canegrub damage in 2012, 2013 and 2014 for the Bundaberg site, including all field data.

Actual damage	2012	2013	2014
Classified correctly	37	17	41
Not classified	8	3	1
% correctly classified	82.22%	85.00%	97.6%
% false negatives	17.78%	15.00%	2.4%

Grub Counting

The number of grubs found from digging up 20 stools within 20 m x 13 row areas were counted in most years for the Mulgrave, Burdekin and Mackay sites. While the number of digging locations at the Mulgrave and Burdekin sites was not large enough to provide meaningful statistics, some statistics for the observations from the Mackay site are shown in Table 26. The table shows that the areas classified as high or moderate likelihood of damage occurred with a significantly higher number of canegrubs than those areas classified as low likelihood of grub damage or not detected. Interestingly, areas classified as moderate likelihood of grub damage had higher first, median and third quantile values of grubs detected in the field than the areas classified as high likelihood of grub damage. This indicates that similar grub densities can be found in areas classified as moderate or high likelihood of damage. It seems that once a set level of NDVI and a degree of texture differences in relation to neighbouring healthy cane are passed, a higher NDVI and/or texture difference does not necessarily mean that there are more grubs. This suggests that once as set density of grubs is reached, damage symptoms may not necessarily become more visible in the images. However, further observations would be required to prove this theory.

Table 26. Minimum, maximum, first quantile, median and third quantile values of the number of grubs found from digging up 20 stools within 20 m x 13 row areas at the Mackay site in 2012, 2013 and 2014.

	High likelihood	Moderate likelihood	Low likelihood	Not detected
Min	0	2		0
Q1	10	21		2
Median	18	30	0	5
Q3	30	43		13
Max	61	71		22
n	41	6	1	8

Distribution and extent of mapped grub damage

The size, number and shape of cane blocks, which was provided by the individual mills/productivity services, varied every year due to farming operations (i.e. sub-dividing, fallowing etc.). This, combined with clouds/cloud shadows at the time of the image capture resulted in a different number of blocks being assessed each year for each of the five study sites. For most sites a significantly larger number of blocks with >20% mapped grub damage was recorded compared to sites with 15-20% mapped grub damage. However, this did not in most cases exhibit a proportionally equal increase in the area of blocks with > 20% mapped grub damage, as blocks with > 20% mapped grub damage on average were generally smaller in size. This is because smaller blocks, including those blocks partially reduced in size due to cloud cover or parts being harvested, did only require smaller areas to occur as grub damage to fall above a threshold of > 20% mapped grub damage per block.

For both the Bundaberg and Childers study sites, the majority of blocks (>57% over all cases) occurred with less than 10% grub damage in 2012, 2013 and 2014. For Bundaberg and Childers, 2014 was the year with the least mapped grub damage and 2012 with the most mapped grub damage (Tables 27-30). A similar trend was observed for the Mackay study site (Tables 31-32) with most grub damage mapped in 2012 and the least grub damage mapped in 2014. The three week gap between the 26 May 2013 and the 14 June 2013 images did not result in any significant changes in the level of mapped grub damage. However, comparing the three satellite images for the Burdekin study site in 2013 (27 March, 26 May, 17 June) showed significant increases in the category of >20% mapped grub damage and decreases in the categories of <10% mapped grub damage between 27 March and 26 May (Tables 33-34). As mentioned previously, this was not attributed to increased grub damage being detected, but rather the large area of sprawling occurring due to increased cane growth between 27 March and 26 May. The levels of mapped damage decreased slightly in the 17 June image, as some of the sprawling cane was starting to grow upwards again. This, combined with the poor mapping accuracies for the Burdekin study site and the high levels of insecticide treatment, indicate that the current mapping approach is not suitable for that area. The Mulgrave region showed a gradual reduction in mapped grub damage between 2012 and 2014 (Tables 35-36), perhaps due to increased insecticidal application in that area.

Table 27. Number and area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Bundaberg study site.

Bundaberg Image Capture Date	19 June 2012	25 May 2013	26 April 2014
Level of Grub Damage per Block	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)
> 5% mapped grub damage	173 / 4.65	199 / 5.68	224 / 6.80
5 - 10% mapped grub damage	233 / 5.03	219 / 5.12	176 / 3.80
10 - 15% mapped grub damage	114 / 3.22	86 / 2.41	81 / 1.34
15 - 20% mapped grub damage	57 / 0.90	40 / 0.78	29 / 0.27
> 20% mapped grub damage	147 / 3.11	104 / 1.23	106 / 1.01
Total no. of blocks	724 / 16.91	648 / 15.22	616 / 13.22

Table 28. Percentage of blocks and percentage of the area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Bundaberg study site.

Bundaberg Image Capture Date	19 June 2012	25 May 2013	26 April 2014
Level of Grub Damage per Block	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks
> 5% mapped grub damage	23.90 / 27.50	30.71 / 37.33	36.36 / 51.47
5 - 10% mapped grub damage	32.18 / 29.73	33.80 / 33.66	28.57 / 28.75
10 - 15% mapped grub damage	15.75 / 19.07	13.27 / 15.85	13.15 / 10.11
15 - 20% mapped grub damage	7.87 / 5.30	6.17 / 5.10	4.71 / 2.03
> 20% mapped grub damage	20.30 / 18.41	16.05 / 8.05	17.21 / 7.65

Table 29. Number and area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Childers study site.

Childers Image Capture Date	19 June 2012	25 May 2013	18 April 2014
Level of Grub Damage per Block	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)
> 5% mapped grub damage	294 / 6.47	392 / 8.66	408 / 8.90
5 - 10% mapped grub damage	343 / 4.44	395 / 5.34	416 / 5.76
10 - 15% mapped grub damage	214 / 2.48	286 / 2.86	243 / 2.30
15 - 20% mapped grub damage	112 / 0.97	136 / 1.07	141 / 1.01
> 20% mapped grub damage	398 / 2.29	429 / 1.60	432 / 1.40
Total no. of blocks	1361 / 16644833	1638 / 19526279	1640 / 19358491

Table 30. Percentage of blocks and percentage of the area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Childers study site.

Childers Image Capture Date	19 June 2012	25 May 2013	18 April 2014
Level of Grub Damage per Block	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks
> 5% mapped grub damage	21.60 / 38.86	23.93 / 44.34	24.88 / 45.97
5 - 10% mapped grub damage	25.20 / 26.66	24.11 / 27.35	25.37 / 29.73
10 - 15% mapped grub damage	15.72 / 14.92	17.46 / 14.66	14.82 / 11.86
15 - 20% mapped grub damage	8.23 / 5.83	8.30 / 5.48	8.60 / 5.21
> 20% mapped grub damage	29.24 / 13.74	26.19 / 8.18	26.34 / 7.23

Table 31. Number and area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Mackay study site.

Mackay Image Capture Date	3 June 2012	26 May 2013	14 June 2013	2 May 2014
Level of Grub Damage per Block	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)
> 5% mapped grub damage	369 / 9.20	513 / 12.88	520 / 12.93	506 / 18.81
5 - 10% mapped grub damage	553 / 11.15	606 / 12.21	601 / 12.00	476 / 13.79
10 - 15% mapped grub damage	304 / 6.13	323 / 5.93	339 / 6.75	214 / 5.53
15 - 20% mapped grub damage	179 / 3.25	173 / 2.97	193 / 3.64	93 / 1.78
> 20% mapped grub damage	443 / 6.26	324 / 3.85	349 / 3.64	234 / 1.72
Total no. of blocks	1848 / 35.99	1939 / 37.85	2002 / 38.97	1523 / 41.62

Table 32. Percentage of blocks and percentage of the area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Mackay study site.

Mackay Image Capture Date	3 June 2012	26 May 2013	14 June 2013	2 May 2014
Level of Grub Damage per Block	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks
> 5% mapped grub damage	19.97 / 25.55	26.46 / 34.03	25.97 / 33.19	33.22 / 45.18
5 - 10% mapped grub damage	29.92 / 30.98	31.25 / 32.26	30.02 / 30.80	31.25 / 33.13
10 - 15% mapped grub damage	16.45 / 17.03	16.66 / 15.68	16.93 / 17.32	14.05 / 13.29
15 - 20% mapped grub damage	9.69 / 9.03	8.92 / 7.86	9.64 / 9.35	6.11 / 4.27
> 20% mapped grub damage	23.97 / 17.40	16.71 / 10.18	17.43 / 9.33	15.36 / 4.13

Table 33. Number and area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Burdekin study site.

Burdekin Image Capture Date	4 May 2012	27 March 2013	26 May 2013	17 June 2013	2 May 2014
Level of Grub Damage per Block	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)
> 5% mapped grub damage	123 / 7.45	305 / 16.61	157 / 8.34	180 / 9.28	252 / 13.48
5 - 10% mapped grub damage	151 / 5.84	229 / 9.73	136 / 5.63	136 / 5.43	112 / 3.09
10 - 15% mapped grub damage	111 / 4.21	109 / 3.05	111 / 4.29	110 / 4.96	92 / 2.25
15 - 20% mapped grub damage	80 / 2.63	82 / 2.70	58 / 1.80	62 / 1.88	56 / 1.08
> 20% mapped grub damage	355 / 9.90	213 / 3.20	415 / 13.87	354 / 10.40	417 / 10.83
Total no. of blocks	820 / 30.04	938 / 35.28	877 / 33.93	842 / 31.96	929 / 30.73

Table 34. Percentage of blocks and percentage of the area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Burdekin study site.

Burdekin Image Capture Date	4 May 2012	27 March 2013	26 May 2013	17 June 2013	2 May 2014
Level of Grub Damage per Block	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks
> 5% mapped grub damage	15.00 / 24.81	32.52 / 47.07	17.90 / 24.58	21.38 / 29.05	27.13 / 43.87
5 - 10% mapped grub damage	18.41 / 19.45	24.41 / 27.58	15.51 / 16.58	16.15 / 17.00	12.06 / 10.05
10 - 15% mapped grub damage	13.54 / 14.00	11.62 / 8.64	12.66 / 12.65	13.06 / 15.53	9.90 / 7.31
15 - 20% mapped grub damage	9.76 / 8.77	8.74 / 7.65	6.61 / 5.31	7.36 / 5.89	6.03 / 3.51
> 20% mapped grub damage	43.29 / 32.97	22.71 / 9.06	47.32 / 40.87	42.04 / 32.53	44.89 / 35.25

Table 35. Number and area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Mulgrave study site.

Mulgrave Image Capture Date	9 June 2012	26 May 2013	4 June 2014
Level of Grub Damage per Block	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)	No. of Blocks / Area of Blocks (km^2)
> 5% mapped grub damage	876 / 26.52	954 / 35.31	1655 / 62.41
5 - 10% mapped grub damage	505 / 17.82	592 / 20.51	571 / 19.55
10 - 15% mapped grub damage	308 / 10.45	282 / 8.40	313 / 8.23
15 - 20% mapped grub damage	160 / 4.95	168 / 4.30	158 / 4.25
> 20% mapped grub damage	508 / 13.96	489 / 13.18	465 / 8.98
Total no. of blocks	2357 / 73.70	2485 / 81.89	3162 / 103.42

Table 36. Percentage of blocks and percentage of the area of blocks classified with different areal extents of grub damage in 2012, 2013 and 2014 for the Mulgrave study site.

Mulgrave Image Capture Date	9 June 2012	26 May 2013	4 June 2014
Level of Grub Damage per Block	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks	% of Blocks / Area of Blocks
> 5% mapped grub damage	37.2 / 36.0	38.4 / 43.2	52.3 / 60.3
5 - 10% mapped grub damage	21.4 / 24.2	23.8 / 25.1	18.1 / 18.9
10 - 15% mapped grub damage	13.1 / 14.2	11.3 / 10.3	9.9 / 8.0
15 - 20% mapped grub damage	6.8 / 6.7	6.8 / 5.3	5.0 / 4.1
> 20% mapped grub damage	21.6 / 18.9	19.7 / 16.1	14.7 / 8.7

Maps showing the distribution of the different categories of grub damage mapped for each individual block are presented in Figures 11-15. Figures 11-15 generally show a high level of variation in the level of mapped grub damage from year to year. Blocks changing between neighbouring categories of grub damage within the same season may have been close to the threshold of a category and hence only little change in mapped grub damage will result in a block being in the category just above or below the one within which it occurred a month or two ago. Hence, only a change of two or more categories (e.g. from 5-10% to 15-20%) should be considered a significant change. A consistent characteristic of the Mulgrave study site is the high levels of grub damage detected along the edges of the creek in the southern half of the image.
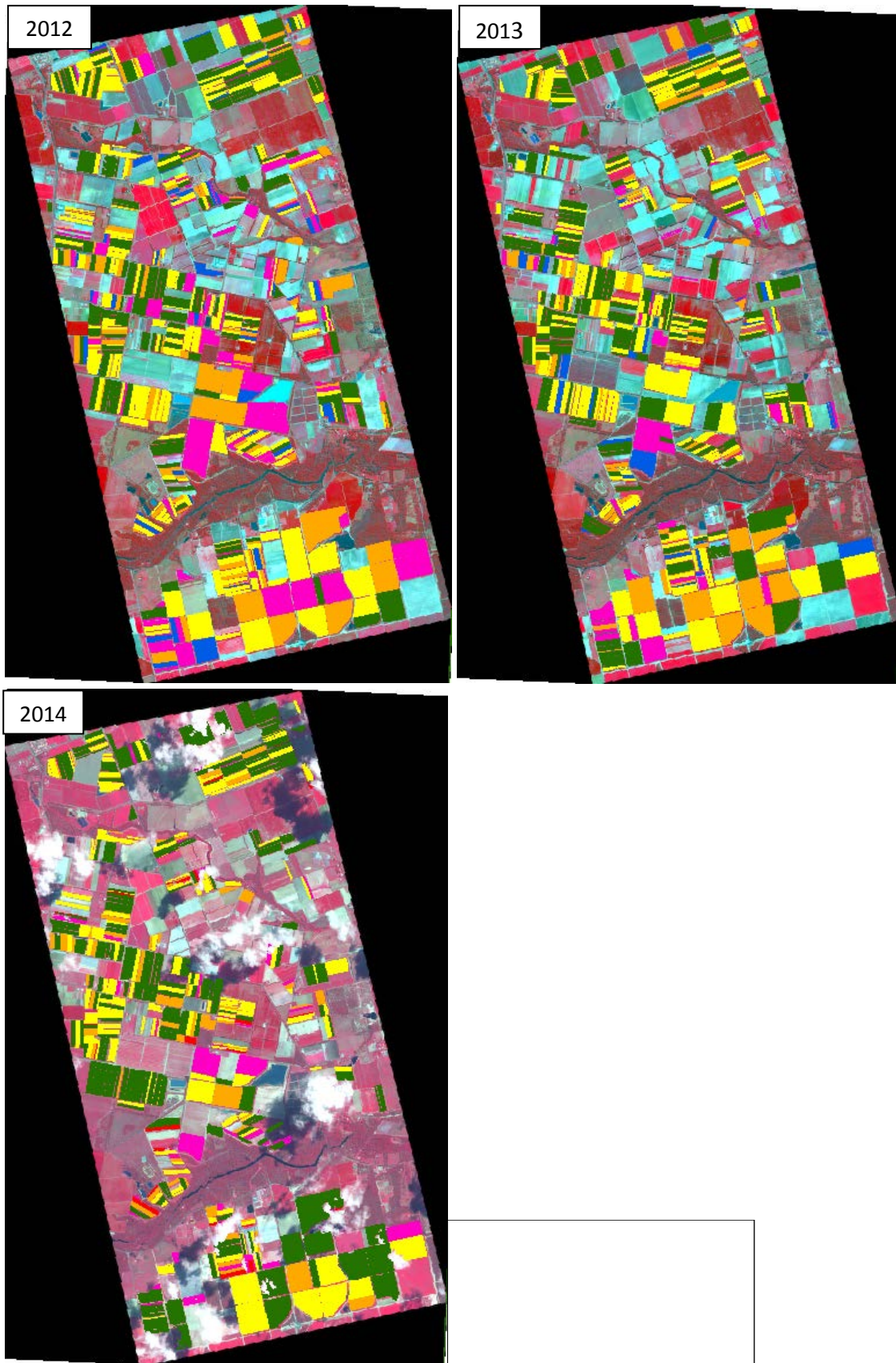
Figure 11. Distribution of blocks of different levels of grub damage for the Bundaberg area from 2012-14.
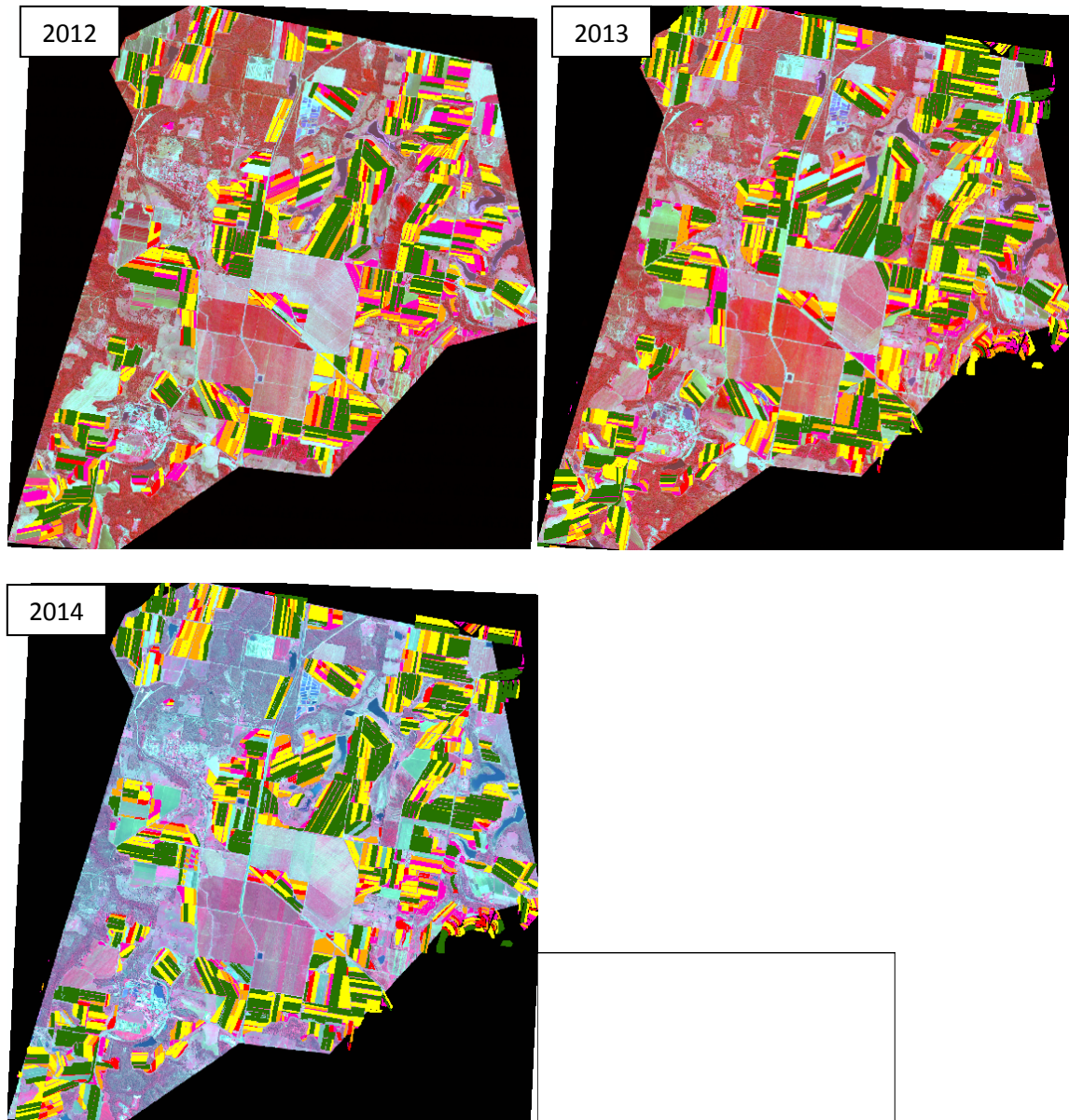
Figure 12. Distribution of blocks of different levels of grub damage for the Childers area from 2012-14.
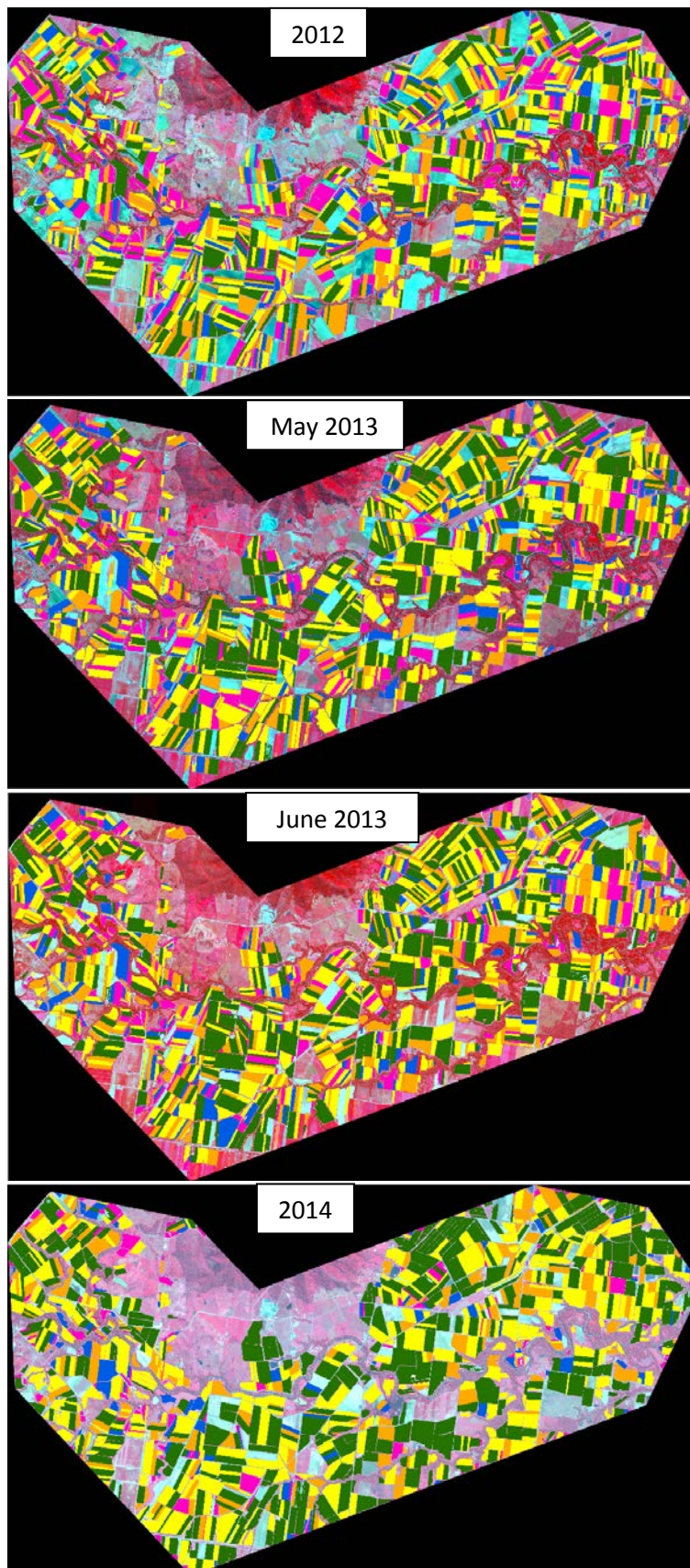
Figure 13. Distribution of blocks of different levels of grub damage for the Mackay area from 2012-14.
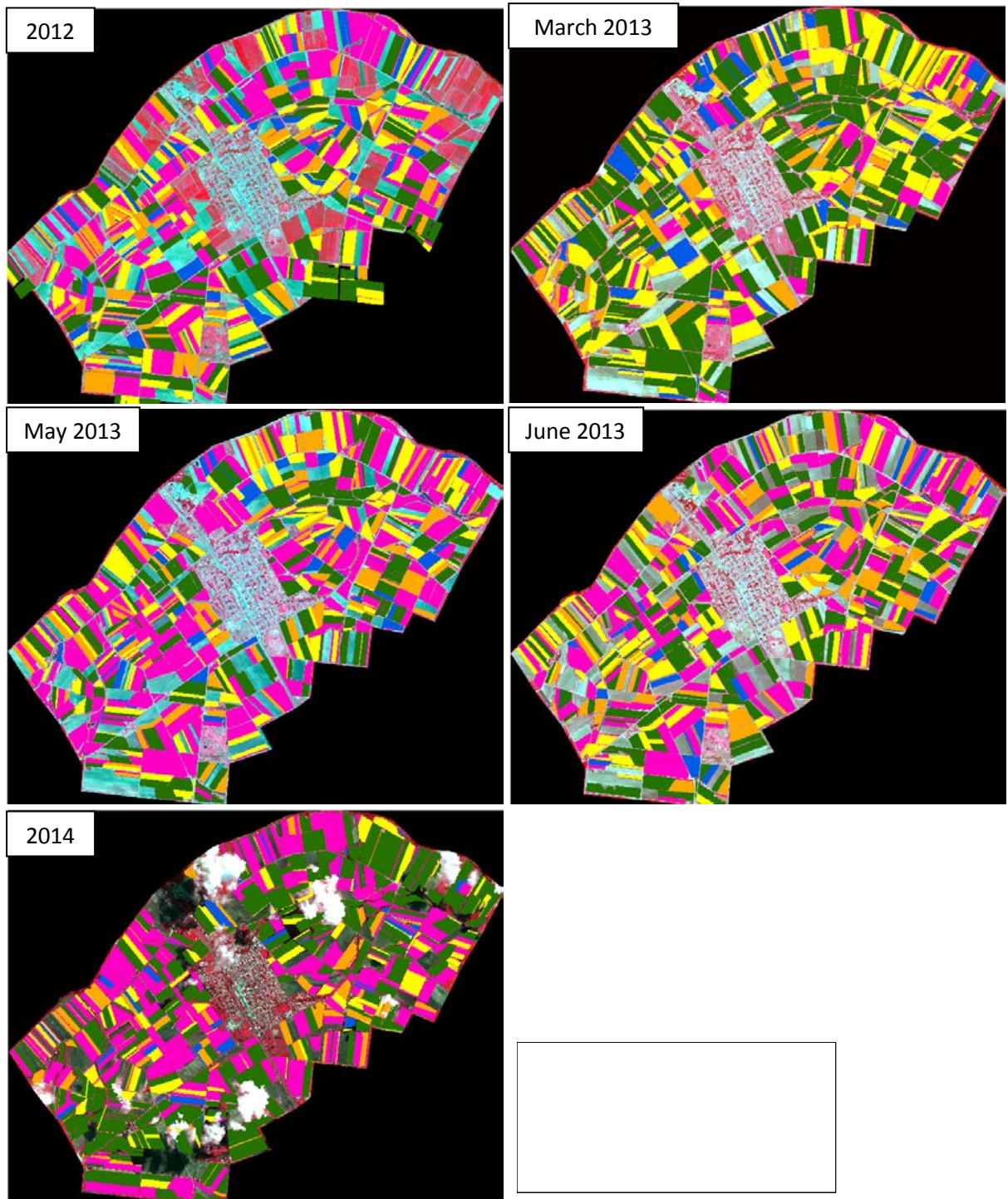
Figure 14. Distribution of blocks of different levels of grub damage for the Burdekin area from 2012-14.
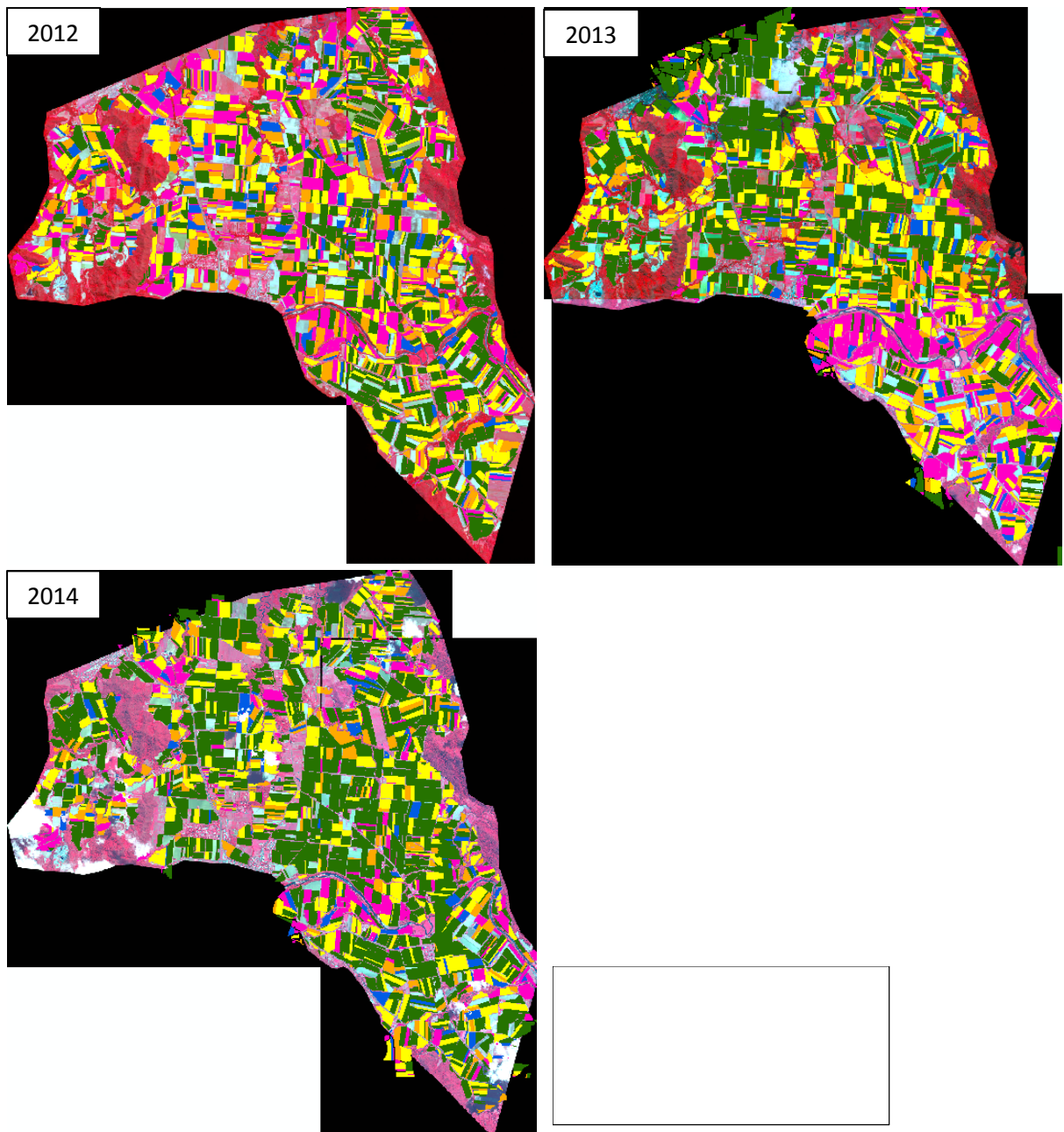
Figure 15. Distribution of blocks of different levels of grub damage for the Mulgrave area from 2012-14.

Section 5: Intellectual Property (IP) and Confidentiality

Records from individual growers' properties remain confidential.

Section 6: Industry Communication and Adoption of Outputs

Key messages

Two main key project messages are:

- Satellite imagery can be used to detect canegrub damage with up to 90% level of accuracy or higher. This accuracy level can only improve.
- Sections of the sugarcane industry are interested in adopting this technology. To date, Mulgrave, Herbert, Childers and Maryborough regions indicated their willingness to financially support this technology and ultimately adopt it. Other regions expressed interest but no immediate plans to financially support the technology were put forward. Phil Ross (PEC/Mackay) is the coordinating officer.

Communication with the industry

Several industry workshops were conducted during the course of this work. The following is a list of some key events:

2011

Information meetings were held at Childers (25/11/11), Mackay (15/11/11), Home Hill (16/11/11) and Gordonvale (18/11/11). These were led by the relevant entomologist at each location along with Andrew Robson and Chris Abbott (DEEDI) and Peter Samson (SRA) who addressed participating growers and Productivity Service staff. The workshops informed participant of the concept behind the project, the technology and how the work will run in practice.

2012

An outline of the work was presented at the Mackay Trial Information Day in February, the SRDC Expos in May, the Mackay BSES Field Day in May, and greyback canegrub SASDP workshops at Meringa and Home Hill in May and June 2012.

A planning meeting for the project was held on 22‑23/10/12 in Brisbane. Progress was later presented to advisors at a Sugar Advisory Services Development Program (SASDP) workshop at Mackay in October and to growers in the Bundaberg, Mackay and Mulgrave areas in December. Progress in the Burdekin was relayed to growers by email on 13/12/12. Growers were presented with satellite images showing grub damage using Google Earth. Participants were surveyed for their attitudes to grub management and to aspects of remote sensing. All growers believed that it is important to determine current damage levels and distribution in order to limit future damage, and most would be willing to share information on damage on their farms.

2013

A grower workshop was held in Gordonvale on 26/9/13 and was attended by several members of the industry. Andrew Ward, David Calcino and Rodrick Fletcher (SRA/PEC) actively participated in the workshop. Progress with remote sensing work was presented and all participants were given grub damage risk map in a printed A3 format.

2014

A series of workshops were held during June 2014 in Gordonvale, Ingham, Ayr and Mackay where growers were requested to select a preferred damage mapping option. Details on feedback are available in Appendices 3 and 4. Risk maps were sent as shapefiles to certain interested growers. Mulgrave Productivity Service is in the process of laying out the risk map over growers farm map on the mill's website.

a)   *What new information, if any, is available on the adoption of project outputs?*

Industries in Mulgrave, Herbert Childers and Maryborough are willing to fully adopt the technology. Industries in Tully, the Burdekin and Mackay support the idea but no plans for financing the actual implementation were drawn.

b)   *List any newsletters, fact sheets or any other media coverage.*
- An article in Canegrowers newsletter presented an overview of the project and advertised the September 2013 workshop that took place in Gordonvale (Appendix 6).
- The SRA e-Newsletter published on 21/10/14 included a feature on this project. An extract from the newsletter is attached to this report (Appendix 7).

c)   *Identify any further opportunities to disseminate and promote project outputs at seminars, field days etc.*

We believe that enough information dissemination has been achieved, and the project is now ready for implementation in three regions of Queensland. Industries in other regions are well aware of this technology but financing the work was identified as the obstacle hindering adoption.

Section 7: Environmental Impact

No negative environmental impact is foreseen. Positive environmental impact may ensue due to strategic pesticide application.

Section 8: Recommendations and Future Industry Needs

A project proposal on the practical adoption of this technology has been submitted to the funding panel (February 2015). Depending on the outcome, the next three years may see industries in certain regions running the system "self-reliantly".

Two specific recommendations were identified in this project:

- Address validation limitations by collecting independent field data of locations with healthy undamaged sugarcane so that both user's and producer's accuracies can be calculated in an unbiased manner.
- Final visual assessment and manual editing may be useful in some cases to further improve maps and remove incorrectly classified grub damage if visually identified.

This may enable a reduction of false positives. As the producer's accuracy was high for all sites, a final visual assessment should mainly focus on removing incorrectly classified grub damage (false positives).

Section 9: Publications

Three main scientific publications were produced based on this work:

1) Johansen K, Robson A, Samson P, Sallam N, Chandler N, Eaton A, Derby L, Jennings J. 2014. Mapping canegrub damage from high spatial resolution satellite imagery. *Proceedings of the 36th Australian Society of Sugar Cane Technologists Conference,* Gold Coast 62- 70. (Appendix 8)

   This presentation was awarded the best research paper of the ASSCT conference at the Gold Coast, 29 April – 1 May 2014.

2) Johansen K, Robson A, Samson P, Sallam N, Chandler K, Derby L, Jennings J. 2014. Mapping Sugarcane Grub Damage from High Spatial Resolution Satellite Imagery. South-Eastern European Journal of Earth Observation and Geomatics, 3(2S). GEOBIA conference, 21-24 May 2014, Thessaloniki, Greece. (Appendix 9)

3) Zellner P, Lelong C, Soti V, Tran A, Sallam N, Robson A, Goebel F. 2014. A remote sensing and GIS approach to the relationship between canegrub infestations and natural vegetation in the sugarcane landscape of Queensland, Australia. Landscape Management for Functional Biodiversity, IOBC-WPRS Bulletin, 100, 153-158. (Appendix 1)

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Allsopp P. 2010. Integrated management of sugarcane whitegrubs in Australia: An evolving success. Annual Review of Entomology 55,329-49.

Allsopp PG, Chandler KJ, Samson PR, Story PG. 1993. Pests of Australian sugarcane. Bureau of Sugar Experiment Stations, Brisbane. ISBN 0 724251790. 90 pp.

Apan A, Held A, Phinn S, Markley J. 2004. Detecting sugarcane orange rust disease using EO-1 Hyperion hyperspectral imagery. Int. J. Remote Sens. 25 (2), 489‑498.

Benz UC, Hofmann P, Willhauck G, Lingenfelder I, Heynen M. 2004 Multi-resolution, objectoriented fuzzy analysis of remote sensing data for GIS-ready information. ISPRS Journal of Photogrammetry and Remote Sensing 58, 239-258.

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Franke J, Menz G. 2007. Multi-temporal wheat disease detection by multi-spectral remote sensing. Precision Agriculture 8, 161-172.

Johansen K, Bartolo R, Phinn S. 2010. Special Feature - Geographic object-based image analysis. Journal of Spatial Science 55, 3-7.

Johansen K, Robson A, Samson P, Sallam N, Chandler K, Eaton A, Derby L, Jennings J. 2014. Mapping canegrub damage from high spatial resolution satellite imagery. ASSCT 36, 11 pp.

Jordan CF. 1969. Derivation of leaf area index from quality of light on the forest floor. Ecology 50, 663–666.

Haralick RM, Shanmugam K, Dinstein I. 1973. Textural features for image classification systems. IEEE Transactions on Systems, Man and Cybernetics, SMC-3, 6, 610 – 621.

Robson A, Abbott C, Lamb D, Bramley R. 2012. Deriving sugarcane yield maps from SPOT5 satellite imagery at a regional scale. International Society of Sugar Cane Technologists, Townsville, September 2012.

Rouse JW, Haas RH, Shell JA, Deering DW. 1973. Monitoring vegetation systems in the Great Plains with ERTS-1. In: Proceedings of Third Earth Resources Technology Satellite Symposium, Goddard Space Flight Center, Washington, D.C., 1, 309–317.

Sallam N. 2011. Review of current knowledge on the population dynamics of *Dermolepida albohirtum* (Waterhouse) (Coleoptera: Scarabaeidae) Australian Journal of Entomology 50, 300-308.

Sallam N et al. 2013. Predicting greyback canegrub damage in the Herbert region of North Queensland. ASSCT 35, 6 pp.

Sallam N, Lowe G. 2012 Implementation of a risk assessment program to forecast greyback canegrub damage in Mulgrave sugarcane fields. ASSCT 34, 98 - 106.

Samson PR. 2008. GrubPlan2: Developing improved risk-assessment and decision-support systems for managing greyback canegrub. SRDC Final Report SD08006, 285 pp.

Samson PR, Chandler KJ, Sallam N. 2007. GrubPlan: options for greyback canegrub management. BSES Limited, Brisbane.

Samson PR, Eaton A. 2012. Implementation of a monitoring and risk-assessment system for greyback canegrub near Mackay. ASSCT 34, 107 - 116.

Samson PR, Sallam N, Drummond FA. 2011. Sampling plans for greyback canegrub to aid management decisions at farm and district level. ASSCT 33, 9 pp.

Tucker CJ, Holben BN, Elgin Jr JH. 1980. Relationship of spectral data to grain yield variation. Photogrammetric Eng. Remote Sens. 46 (5), 657-666.

Wiegand CL, Richardson AJ, Escobar DE, Gerbermann AH. 1991. Vegetation indices in crop assessments. Remote Sens. Environ. 35, 105-119.

Yang C, Everitt JH. 2002. Relationships between yield monitor data and airborne multidate multispectral digital imagery for grain sorghum. Precision Agriculture 3 (4), 373-388.

Zhang M, Qin Z, Liu X. 2005. Remote sensed spectral imagery to detect late blight in field tomatoes. Precision Agriculture 6, 489-508.

Zhang M, Qin Z, Liu X, Ustin SL. 2003. Detection of stress in tomatoes induced by late blight disease in California, USA, using hyperspectral remote sensing. Int. J. Appl. Earth Observ. 4 (4), 295‑310.

Zellner P, Lelong C, Soti V, Tran A, Sallam N, Robson A, Goebel FR .2014. A remote sensing and GIS approach to the relationship between canegrub infestations and natural vegetation in the sugarcane landscape of Queensland, Australia. IOBC/WPRS bulletin 100, 153-158.

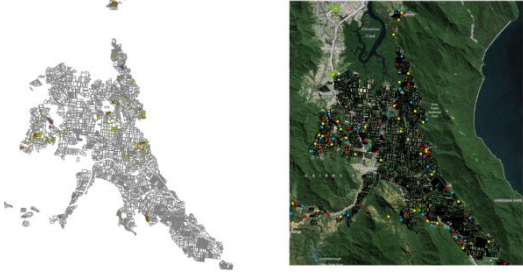Appendix 2 - How would you like your grub damage risk map presented PDF

How would you like your grub damage risk map presented?
Printed format or web-based? Or both?

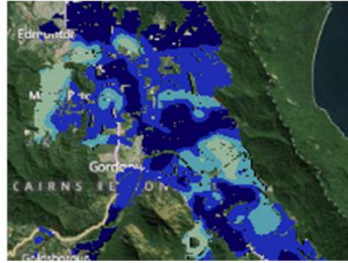## <u>Printed format options</u>

Options 1 and/or 2
Printed map of the region showing indicative damage as points.

Option 3
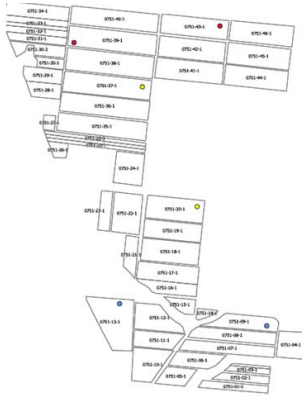Printed map of region showing indicative damage in gradient colouring.

Option 4
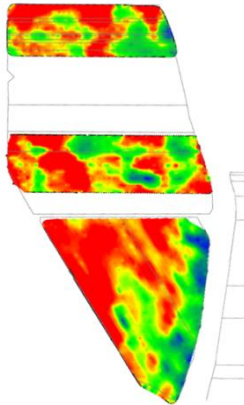Printed map of region showing <u>actual</u> damage shapes as detected by the GEOBIA method.

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Option 5
Same as option 1 but for your farm only

Option 6
Same as option 3 but for your farm only

Option 7
Same as option 4 but for your farm only

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<u>Printed format options</u>
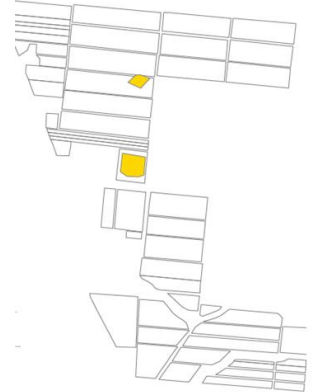
Web-based options

Option 8

Google Earth map of the region showing indicative damage as points. Also enables You to zoom into your own farm.
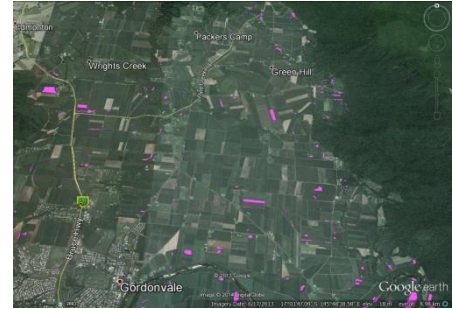

Option 9

Google Earth map of region showing indicative damage in gradient colouring.

Option 10

Google Earth map of region showing <u>actual</u> shapes of <u>all</u> types of damage as detected by the GEOBIA method.

Option 11

Option 8 above but for your farm only (showing indicative damage as points).
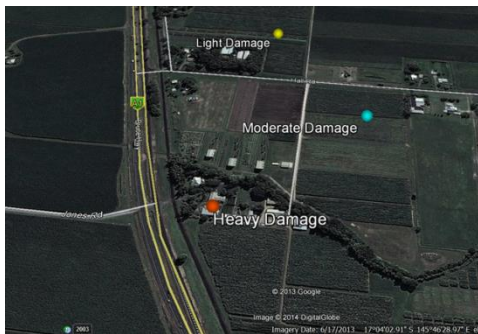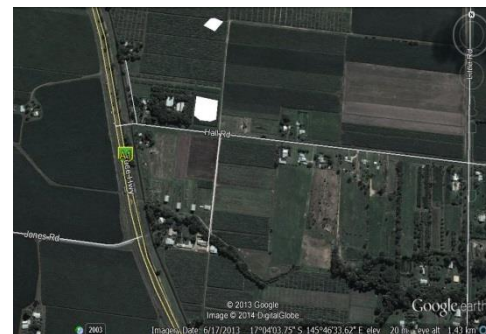

Option 12

Option 9 above but for your farm only (indicating damage as a colour gradient).

Option 13

Option 10 above but for your farm only (actual shapes of damage as detected by the GEOBIA method)

Date _____

Name & contact (Optional) _____

Region _____

Are you a (Grower – Miller – Productivity Service – CANEGROWERS) – if other please specify _____

Which of the above map(s) do you prefer to receive as a Risk Map. If you prefer more than one please indicate and discuss:

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Appendix 3 - Preferences for map options

Name	Option #1	Option #2	Option #3	Option #4	Option #5	Option #6	Option #7	Option #8	Option #9	Option #10	Option #11	Option #12	Option #13	
Mulgrave														
Ron Downing			X									X		
Don Hussey			X							X			X	
Mark Rossi												X	X	
Richard Hesp			X	X								X	X	
Jordon Villaruz					X					X				
Mark Savina													X	
Andrew Greenwood								X	X		X			
Claire Bailey			X				X							
Roderick Fletcher		X						X				X		
Michael Porta	X			X			X			X		X	X	
Jeff Smith										X			X	
David Calcino				X						X				
John Ferrando				X						X				
Jeff Day				X						X				
Richi Falla				X						X				
Anon			X									X	X	
Matt Hessian									X			X		10, 12 & 13
Herbert														
Stephen Accornero						X						X		
Anon	X											X		
Anon			X			X			X					
Glen Irlam											X			
Brendan Accornero									X	X		X	X	
Santo Spampinato Matthew Poppin										X		X		
Warren Russo		X											X	
Anon						X								12
Burdekin														
Anon			X			X				X		X		
Jim Richarson	X				X			X			X			
Rob Milla		X				X	X			X			X	
Rob Ahern	X						X			X			X	
Denis Pozzebon										X				
Anon										X				
David Paine										X				
Joe Savorguan										X				
Ray Hildebrandt													X	
Stephen Fabbro	X						X			X				
Keith Pearce	X	X								X				10
Mackay														
Shane Sievers										X				
Andrew Camiceri		X	X		X	X	X		X	X		X	X	
Anon							X		X				X	
Anon									X					
Steven Garrad		X			X									
Duane Chapman									X	X				
Rob Ribaldone								X	X	X				
Charles Deguama						X	X							
Dave Woolston							X			X				
Ray Abels						X								
John Muscat										X				
Peter Sutherland										X				
Phil Deguara												X	X	
John Markey										X				
Shane Hare			X									X		
Michael Deguara	X	X	X			X	X	X				X		10

Appendix 4 - Detailed map preferences

Appendix 4
Detailed comments given by industry participants on preferred options of grub damage risk maps.

Mulgrave

Michael Porta- Grower, Miller, Productivity and CANEGROWERS
Option 1 and 2…This is okay, it is not incrimination
Option 3…No…needs boundaries to zoom in very close
Option 4…Can zoom in. Prod Boards
Option 6…Good
Option 7…Yes-Good for precision placement
Option 9…No-Gradient colour is a bit "errr" with no boundaries. Gradient colour that respects boundaries-okay
Option 10…Looks good and accuracy is good. Exact shape of damage is <u>excellent</u>
Option 12…Best for growers
Option 13…2nd best for growers
Gradient colouring or actual shapes of damage
Gradient colouring will need to be able to zoom in very close and including farm and block boundaries would be better
Prod boards, mills, SRA need the regional information preferable as gradient colouring or actual damage
Privacy may only be an issue for certain information like harvested tonnes rather than pest damage
RE privacy-just get individuals to choose if they allow their information to be available for wider public viewing

Sean Marshall – visiting scientist
Electronic most valuable (versatile) and can easily be printed out for use.
Best option for grower is exact damage on farm
Privacy issues need to be sorted…if not 100% then a general map is the best that can be done (either printout or limit google zoom)
Check with lawyers and mills and all growers (not just those that show up to meetings)
Productivity needs exact map of region
Next maps are good but not sure how useful it is except in general terms
For future, need to discuss as an industry tool…combine with all facets and you'll have a powerful tool.
Target single issues and it won't be economically viable to run as a service.
Why does it have to be either paper or web?
Why not both options and let individual growers choose?

Roderick Fletcher-SRA
Option 8…This map will give good local representation of threats in the growers region.
Combine with option 12 as 2nd tier map
Option 12…This map will give good grower level risk management abilities. 3rd tier map
I think the combination of 3 maps would be optimal.
The 3 maps will give 3 levels of risk awareness and risk management abilities
Public View Page
The website interface page could open with option ½ to show a mi8ll region's grub problems
Login required
The grower could then look closer and look at other areas close to his farm and assess the risk to his farm and see how heavy or how many colonies may be present close to him by opening option 8
Login required
Lastly, by being able to open a page with option 12 the grower could assess his own farm and where the majority of the damage has occurred and run where the treatment applications are.
Funding for this project: Sell it to the whole industry, it will be funded by SRA

Claire Bailey-Mossman Agricultural Services
Option 3…Would it be handy for growers if the district boundaries are in one place to give them a rough guide as to where they are on the map. This map is a good option

Option 7…This might be a good option for guys also using precision Ag-would they be able to upload so they can treat damage/risk areas?
Whole region risk map, option 3-Would like to see mill districts outlined (not particularly farm layers)
For farm only, option 12-It allows growers to see whole risk and problem areas
Would like to see option 7 be able to be used within the precision Ag system (or targeted/variable rate application)
Accessibility from either SRA or Mill websites will be really important, looking forward when it's known who will be creating their maps they should house the links
Cost for areas?

Andrew Greenwood-Grower
I am not interested in printed options
Option 8… Best for Productivity Board etc.
Option 11…Best for farmer. I would like to see option 8 so I can see where the grub pressure will be coming from
I would like to be able to access option 8 and be able to zoom into option 11
I prefer to be able to login to access this information, the same as variety information
The trouble with emails is after a time they it is too hard to find or someone has deleted them
I think after a few years we will end up with option a10 and 13 so we should be trying to get this as accurate as possible, while funding is still available for options 8, 9, 11 and 12

Mark Savina-Grower
Option 1…This would be good for Prod Board to look for outbreak areas.
Farm could be advised to look in their area
Option 8…Dot would be good to show where to look
This would be good over a number of years.
Option 9…This is good to show where the damage is. It gives us a tool to overlay maps to see whether the damage is moving

I think that all of data has to go to the local prod services group so they can act with an all of district approach. They can then alert the growers of a growing risk. If they have a web base layer map, they can build up a data base over a number of years then advise or target districts that have the potential of an outbreak. SRA should manage the overlay; that way, if a grower is in an area that does not have an active Prod board he would at least be able to get info on his farm. I do not know where the funding would be coming from. As a grower I would like to see a web base map with my farm boundaries to give me ideas to where I should target my digging. If it could come back to me as a Shx. file that would be great I could load it on to my farm recording program. I would GPS reference my digs and put them onto my program with a comment on the numbers of grubs found. Again I do not know on funding and privacy laws. I think for my farm option 13 for the mill option 9.

Richard Hesp-Grower
Every farmer needs to get regional grub damage map mailed out to them…Option 3, maybe 4
Individual growers need to be able to access a regional map showing risk and actual damage…Option 9 and 10
Individual growers also need to access risk and actual damage for the individual farms…Option 12 and 13
Options 2 and 3 should be on the mill website, overlaying the two options over the mill's farm boundary maps and Google Earth… maybe that can only be done for option 3

Jordan Villaruz- Tully Productivity Service
Option 5…A4 size maps as growers want privacy (like the current mill maps)
Option 10…This method is the best option for Productivity Services.
Web based program is easy to access via computer or smartphone

Mark Rossi-Grower
Option 9…Good option
Option 12…I think this option is the best for your own farm. It would be good if it could be overlayed with soil maps etc.
Option 13…Good to identify exact damage areas possibly

Don Hussey-Grower

Option 3…This printed map would be good for farm management to see damage in my area
Option 7…This is the best option for my farm to access the grub damage map in mail
Option 10…this option with no farm boundaries marked
Option 13…This is a good option
A printed map of actual grub damage-graded colour for both region and my farm (option 7)
Web based option 10 for my region and option 13 and option 13 for my farm only

Ron Downing-Grower
Option 3 and 12 are good. The colour imagery jumps out for easy I.D.
Any map is good, but for a dinosaur like me with no computer, net etc., I would be happy to drive around and visually inspect
The work presented is excellent

Matt Hessian-Miller, Productivity Services
The information collected is too valuable to be shelved
The more information distributed to growers to do their own risk assessments, the better
However, from a mill (MCM) point of view, we will not agree to any publically available option that identify the boundaries or farm identity
That being the case, a gradient map for the region would be a preferable option
On a farm level, I like options 12 and 13and this could possibly be facilitated through the mill internet site where growers already have access to maps with individual login
I think anything publically available that even broadly identifies an individual farmer will just open you up to a world of pain for the growers who have the 'big red dots', especially if they are already feeling pressure from neighbours
Finally, from the Prod Board, I am still happy to provide the information for the background work to be done with our privacy understanding.

Jeff Smith-SRA
Option 10
Option 13

David Calcino-SRA
Option 4
Option 10

Richie Falla-Productivity Service
Option 4
Option 10

Jeff Day-Grower, CANEGROWERS
Option 4…Need region
Option 10…Also good

John Ferrando-Grower
Option 4
Option 10

Herbert

Anonymous-Grower
Option 6
Option 7

Warren Russo-Grower
Option 11
Option 13…Include some neighbour with 2 km off my farm to see what pressure I've got to contend with

Mathew Poppin-Grower
Option 10
Option 12...Bigger radius around own farm

Santo Spampinato
Option 12

Stephen Accornero-Grower
Option 12…500m around all of farm indicating grub pressure on neighbours
Option 6 and 12 as preference
Both above options showing neighbours approximately 500m around your farm indicating possible grub pressure from neighbours who don't try to contain grubs
In option 6 if you could tie grubs and soil types together we might be able to use a variable rate applicator to apply the susceptible soil types at risk
Option 12 is my preference for grub pressure

Anonymous
Option 1 or 2…For Prod Boards and data records
Option 12…With a 2km radius of neighbouring farms

Anonymous
Option 3…This option is good
Option 6…This option goes with option 3
Option 9…This has good potential
Option 12…Use this option with option 9

Brendan Accornero-Grower
Options 9, 10, 12 and 13
I believe these four will be very useful maps
In saying that, I think it would also be good to see Map 10 overlaid over Map 9, and Map 13 overlaid over Map 12 so we are able to move detail into each map

Glen Irlam-Grower
Option 11…The points of actual damage is a good system to use
Option 12…Appears to be a good option because of variation of colour for damage
Damage shown on property farms to be shown would also be good

Anonymous-Grower
Option 6
Option 7

Burdekin

Anonymous-Productivity Service
Option 10…With different levels showing "Low, Moderate and High"

David Paine-Grower, Productivity Service
Option 10 with colour grading

Joe Savorgnan-Productivity Service
Option 10

Ray Hildebrandt-Productivity Service
Option 10…Best for district
Option 13…Best for own farm
A tool for new area for damage and /or grubs

Stephen Fabbro
Printed format- option 1 and 7 farm only
Web format- option 10 and log on with password to obtain the information

Keith Pearce-Grower
Option 1 or 2 for printed format
The option 10 map

Denis Pozzebon-Grower
Option 10 with the ability to receive Shp. Files to import into "Farmworks" and colour graded for hotspots

Rob Ahern
Option 1 for the district
Option 7 for individual
Option 10 for the district
Option 13 with KMZ files to be sent to e-mail address

Rob Milla-Productivity Service
Option 2…Good for snapshot of region, however limited value for individual
Option 3…Not specific enough
Option 4…Too fine detail for large map-option 2 is better
Option 5…Not enough detail
Option 6…Good if used in combination with option 7
Option 7…Best option for individual
Option 8…Good for regional snapshot
Option 9…Gradients could suggest damage/risk is very widespread. Probably least preferable
Option 10…Great option to zoom into individual farms-best for me as extension officer
Option 11…Option 13 is better
Option 12…Used in combination with 13 is okay, otherwise not very preferable
Option 13…Good
The best extension tool would be option 10 as you are able to zoom and very specific
Don't like gradient risk maps-not specific enough
Shape file would be useful to use with our Ag-Data software package

Jim Richardson-Grower
Option 1&2…Good from farming aspect to know where damage is
Option 5…As a farmer, this is my preference
Option 8…Helpful to know where grub damage is in district
Option 11…Very helpful for individual farmer
From a farming point of view, the individual farm map is most important
Nematodes are affecting crop growth in my cane as much as grubs

Anonymous
Option 3…Good map for seeing damage done
Option 6…Another map which is good
Option 10…Good map
Option 12…Colours are good for seeing details on a map
Colour on maps or photos are good for seeing damage with cane grubs
Darker shades for severe damage and lighter shades for less damage

Mackay

Shane Sievers-Grower
Option 10…Good option with farm map boundary outlined
I would like option 10 with a farm map overlaid if possible

Andrew Camilleri-Grower
Prefer option 4 over 3
Prefer option 7 over 6
Prefer option 10 over 9
Prefer option 13 over 12
Options 1,2,5,8 and 11 are crossed out
I think we need a regional and farm option so I have numbered as such in order of preference
I have placed a cross on some maps-I feel these maps are the least effective
I also think we should have??? Option 10 for all the web based options

Anonymous-Retail

Option 7…This option should be available for growers who can't use a computer
On the retail side I prefer options 9 and 10. For growers a regional and own farm map like option 10 and 13

Charles Deguara-Grower
My options in order of preference are; 7,5,8,9 and 12
For my farm I prefer option 7
Also we need to look at the farms around us to access grub threat to our own farm as in option 8

Mark Hetherington-Productivity Service
Options 10…Zoom into each paddock
Will be able to access previous year's maps
Need access to district/mill area map
All Plane Creek planting details, farm map, plant inspections, varieties, block numbers are stored in AgData and if this layer was in AgData it would be ideal
Incorrect variety recorded for a block would be an ongoing problem
Use Google Earth <u>now</u> to identify poor yielding blocks/patches in blocks that are probably caused by grub damage

Rob Ribaldone-Grower
Option 9, 10 and 12

Steven Garrad-Productivity Service
Option 2…Sets the context
Option 3…Need farm boundaries
Option 4…Groundtruthing to continue to 95% accuracy, best only if on web page so you can zoom
Option 5…High ??? interest
Option 7…Exact shape of damage
Option 9…Could show where damage likely <u>but</u> not detected
Option 12…Object is to promote a line of enquiry by the grower; works only if the grower can answer some of those questions
Need the context of individual farms with the regional damage
The regional damage can be on a printed format with a distribution to Prod Services, retailers of insecticide, mills, SRA PEC etc.
Preference for option 2 as can ID farms using landscape
Then go to web-based option for individual farms
It preserves privacy, leads to enquiry to answer (make sense of) patterns of damage
Prefer option 6 because it leads to ID of areas where grubs are likely to be inflicting damage that is not obvious

Duane Chapman-Grower
Option 9…To compare to all types of damage and isolate the grub damage on a wide area
Option 10…Be good to see all damage and self- assess
9 has ease of access on internet for a wide area to see local concentration
10 is good to see other interest that is on your farm

Anonymous
Option 9…This seems to be the most useful option but organizations such as MAPS needs to see it regionally so we can target areas of concern

Dave Woolston-Grower
Option 8
Option11
Option 10…Would like this to be specific to grubs, not all damage…200m into own farm
Option 13
Options 8 and 10….Region…200m into own farm

Ray Abels
Option 6 shows block and shape of damage
Option 7 gives a location in block
Option 8 shows area damage around you to survey damage

I would like to see a hard copy on request

John Muscat-Grower
Options 1 & 2…Least preferred
Options 5, 6 and 7…Cannot see pressure from neighbouring properties
Option 10…Most preferred
Options 11, 12 & 13…Cannot see pressure from neighbouring properties
Electronic (web based) would be the most cost effective way
Being able to go back in time would identify if treatment is working or not
Regional maps would show me if neighbouring properties, creeks and trees are increasing pressure on my farm

Peter Sutherland-Productivity Services
Option 10…Regional map, KMZ file, able to zoom in
Google Earth files as in map 10
GIS shape file for use by Productivity Service staff
Attach a technical note to aid interpretation of threat
Detailed damage level as point data
Threat map may evolve over time as multiple years of damage
May be accumulative 3 year rolling threat
Estimate of cost

Phil Deguara-Grower
Option 12 & 13 in a web based system with shape files if needed
Want to be able to upload areas treated

John Markley-Independent Agronomist
Option 10

Shane Hare-Productivity Services
Option 3…Prod Services maps; better for regional management; where is the pressure coming from?
Option 12…This is useful for Prod Services when speaking with individual growers and organizing targeted management. Soil type-varieties-tree lines etc.
For regional management Option 3 would be useful to identify where grub pressures may be coming from or moving to
Option 12 is good for individual farm management to target specific on farm damage; soil types, varieties, tree lines etc.

Michael Deguara-Grower, Productivity Service, CANEGROWERS
Option 1 & 2…Good for Prod Services
Option 3…Good for Prod Services
Option 6…Good for grower
Option 7…Good for grower
Option 8…Prod Services
Option 9…Prod Services
Option 12…Grower
Regional maps very good tool for Prod Services to target area hot spots
Individual maps good tool for growers
Cost will be a big driver if growers will take it up
I see more uptake from Prod Services

Appendix 5 - Rule set

Appendix 6: eCognition Rule Set for Classifying Grub Damage

Classes:
Directional Grub Damage Objects
Edges of Potential Grub Damage
Fallow
High Risk 2
High Risk 3
High Risk
Largest_Object
Largest_Object2
Largest_Object3
Largest_Object4
Largest_Object5
Likely grubdamage
Low likelihood of grub damage
Low Risk 2
Low Risk 3
Low Risk
Medium Likelihood of Grub Damage
Moderate Risk 2
Moderate Risk
Moderate Risk 3
No Risk
Non-Siugarcane Fields
On Watch
Potential Grub Damage
  and (min)
    Threshold: Standard deviation Red > Quantile_60%_SD_red
    Threshold: Mean LeSiSum_Red_Smoothed21 > Quantile_60%_LeSiSum_Red_Smoothed21
    Threshold: Mean NDVI < Quantile_40%_NDVI_new
Shadow
Sugarcane fields
  and (min)
    Threshold: Border index < 2
    Threshold: Shape index > 2
    Threshold: Length/Width > 3
    Threshold: Width < 12 Pxl
Sugarcane fields _Temp
  and (min)
    Threshold: Border index < 2.6
    Threshold: Shape index > 2
    Threshold: Length/Width > 3
    Threshold: Width < 12 Pxl
Very High Risk

Customized Features:
Main_Direction_Sugarcane_Field_Level_-7degrees: [Main field direction - sugarcane field level]-7
NDVI_Object: ([Mean NIR]-[Mean Red])/([Mean NIR]+[Mean Red])
Main_Direction_Sugarcane_Field_Level: 'Mean' of 'Main direction' of Sugarcane fields super-object [0]
NDVI within 100 pixels: 'Mean' of 'Mean NDVI' of Sugarcane fields neighbours [100 Pxl]

Process: Main:
Grub Damage On Tiles
  Workspace Automation
    create scene tiles: create (5000x5000) tiles
    submit scenes for analysis: process tiles with 'OnTiles' and stitch with 'OnStiched'

Process: OnTiles:
 Grub Damage Mapping

General
    set rule set options: set rule set options
    delete image object level: on main : delete 'Processing Level'
    delete image object level: on main : delete 'Processing Level'
    delete image object level: on main : delete 'Risk Level'
    delete map: on Processing Map : delete map
Create Processing Map
    copy map: Copy map to 'Processing Map'
Mapping Sugarcane Field Extent
    Segmentation
        chessboard segmentation: chess board: 99999999 creating 'Sugarcane Field Level'
        chessboard segmentation: on Processing Map : chess board: 9999 creating 'Sugarcane Field Level'
    Variables
        update variable: sv_Non-Sugarcane_AreaLowerThreshold = 2000000
        update variable: sv_Fallow_NDVILowerThreshold = 0.37
        compute statistical value: at Sugarcane Field Level: object_Mean = mean(Mean NDVI)
    Non-sugarcane fields
        assign class: on Processing Map unclassified with Area > sv_Non-Sugarcane_AreaLowerThreshold at Sugarcane Field Level: Non-Siugarcane Fields
    Fallow
        layer arithmetics: on Processing Map : layer arithmetics (val "(NIR-Red)\(NIR+Red)", layer NDVI[float])
        assign class: unclassified with Mean NDVI < sv_Fallow_NDVILowerThreshold at Sugarcane Field Level: Fallow
    Sugarcane fields
        assign class: unclassified at Sugarcane Field Level: Sugarcane fields
    Base Objects
        on Processing Map
          Processing
            copy image object level: at Sugarcane Field Level: copy creating 'Processing Level' below
            multiresolution segmentation: Sugarcane fields at Processing Level: 20 [shape:0.1 compct.:0.5]
            assign class: with Existence of super objects Sugarcane fields (1) = 1 at Processing Level: Sugarcane fields
            assign class: Sugarcane fields with Mean NDVI < 0.3 at Processing Level: Fallow
            assign class: 5x: Sugarcane fields with Mean NDVI < 0.45 and Rel. border to Fallow > 0.4 at Processing Level: Fallow
            assign class: Fallow with Rel. border to Sugarcane fields = 1 at Processing Level: Sugarcane fields
            [assign class: Sugarcane fields with Mean NIR < 2500 at Processing Level: Shadow]
            [find enclosed by class: Shadow at Processing Level: enclosed by Sugarcane fields: Sugarcane fields +]
            [assign class: 10x: Sugarcane fields with Mean NIR < 3200 and Rel. border to Shadow > 0.4 at Processing Level: Shadow]
            [merge region: Shadow at Processing Level: merge region]
            [merge region: Fallow, Shadow at Processing Level: merge region]
            copy map: copy map to 'Temp_Map'
            synchronize map: on Temp_Map Fallow, Shadow at Processing Level: synchronize map 'Processing Map'
            delete map: on Temp_Map : delete map
          Edges
            edge extraction lee sigma: edge extraction lee sigma (5.0, Dark) 'Red' => 'LeSiD_Red'
            edge extraction lee sigma: edge extraction lee sigma (5.0, Bright) 'Red' => 'LeSiB_Red'
            layer arithmetics: layer arithmetics (val "LeSiD_Red+LeSiB_Red", layer LeSiSum_Red[float])
            pixel filters sliding window: LeSiSum_Red_Smoothed21 = Gaussian(LeSiSum_Red, 21 x 21 x 1)

loop: Sugarcane fields at Sugarcane Field Level

compute statistical value: sub objects [level:1]: Quantile_40%_NDVI_new = quantile[40](Mean NDVI)

compute statistical value: sub objects [level:1]: Quantile_60%_SD_red = quantile[60](Standard deviation Red)

compute statistical value: sub objects [level:1]: Quantile_60%_LeSiSum_Red_Smoothed21 = quantile[60](Mean LeSiSum_Red_Smoothed21)

[assign class: with Mean NDVI < Quantile_30%_NDVI_new and Mean LeSiSum_Red_Smoothed21 > Quantile_70%_LeSiSum_Red_Smoothed21 sub objects [level:1]: Potential Grub Damage]

classification: sub objects [level:1]: Potential Grub Damage

Processing Level 2

copy image object level: at Processing Level: copy creating 'Processing Level 2' above

assign class: Potential Grub Damage, Sugarcane fields at Processing Level 2: unclassified

\\ objects of high similarity are merged. objects in heterogenous areas stay small, in homogeneous areas grow big

Multiple-Conditions-Based Fusion: at Processing Level 2: Multiple-Conditions-Based Fusion(0.1,,0,,0,Standard deviation NIR,50,Standard deviation Green,20,Standard deviation Blue,20,Standard deviation Red,20,Mean NIR,300,Mean Red,100,Mean Green,100,Mean Blue,100)

assign class: on Processing Map unclassified with Area < 1000 Pxl at Processing Level 2: Potential Grub Damage

merge region: Potential Grub Damage at Processing Level 2: merge region

assign class: Potential Grub Damage with Area < 50 Pxl at Processing Level 2: unclassified

Grub Damage

Processing

assign class: on Processing Map Sugarcane fields with Existence of super objects Potential Grub Damage (1) = 1 at Processing Level: Potential Grub Damage

delete image object level: delete 'Processing Level 2'

assign class: Non-Siugarcane Fields at Processing Level: unclassified

assign class: Potential Grub Damage with Rel. border to unclassified > 0.1 at Processing Level: Edges of Potential Grub Damage

assign class: Potential Grub Damage with Rel. border to Fallow > 0.1 at Processing Level: Edges of Potential Grub Damage

classification: Edges of Potential Grub Damage at Processing Level: Sugarcane fields _Temp

update variable: Edges of Potential Grub Damage at Processing Level: Low NDVI = [NDVI within 100 pixels]-0.15

assign class: Edges of Potential Grub Damage with Mean NDVI < Low NDVI and Mean NDVI < 0.5 at Processing Level: unclassified

assign class: Edges of Potential Grub Damage at Processing Level: Potential Grub Damage

5x: do

assign class: Potential Grub Damage with Rel. border to Sugarcane fields _Temp > 0.1 at Processing Level: Edges of Potential Grub Damage

classification: Edges of Potential Grub Damage at Processing Level: Sugarcane fields _Temp

update variable: Edges of Potential Grub Damage at Processing Level: Low NDVI = [NDVI within 100 pixels]-0.15

assign class: Edges of Potential Grub Damage with Mean NDVI < Low NDVI and Mean NDVI < 0.5 at Processing Level: unclassified

assign class: Edges of Potential Grub Damage at Processing Level: Potential Grub Damage

assign class: Sugarcane fields _Temp at Processing Level: Sugarcane fields

Omitting linear directional features from being grub damage

update variable: Potential Grub Damage, Sugarcane fields at Processing Level: Main field direction - sugarcane field level = Main_Direction_Sugarcane_Field_Level

update variable: Potential Grub Damage, Sugarcane fields at Processing Level: Main field direction - sugarcane field level _Min-5degrees = Main_Direction_Sugarcane_Field_Level_-7degrees

update variable: Potential Grub Damage, Sugarcane fields at Processing Level: Main field direction - sugarcane field level _Max+5degrees = [Main field direction - sugarcane field level]+7

assign class: Potential Grub Damage with Main direction < Main field direction - sugarcane field level _Max+5degrees and Main direction > Main field direction - sugarcane field level _Min-5degrees at Processing Level: Directional Grub Damage Objects

assign class: Directional Grub Damage Objects at Processing Level: Sugarcane fields _Temp

assign class: Sugarcane fields _Temp at Processing Level: Sugarcane fields

assign class: Directional Grub Damage Objects at Processing Level: Potential Grub Damage

Cleaning up

merge region: Sugarcane fields at Processing Level: merge region

merge region: Potential Grub Damage at Processing Level: merge region

merge region: unclassified at Processing Level: merge region

assign class: Potential Grub Damage with Area < 50 Pxl at Processing Level: Sugarcane fields

find enclosed by class: Sugarcane fields at Processing Level: enclosed by Potential Grub Damage: Potential Grub Damage +

assign class: Potential Grub Damage with Area < 150 Pxl and Distance to Potential Grub Damage > 70 Pxl at Processing Level: Sugarcane fields

Resegmentation of potential grub damage objects

chessboard segmentation: Potential Grub Damage at Processing Level: chess board: 2

multiresolution segmentation: Potential Grub Damage at Processing Level: 10 [shape:0.1 compct.:0.5]

spectral difference segmentation: Potential Grub Damage at Processing Level: spectral difference 50

merge region: Sugarcane fields at Processing Level: merge region

Finding objects with large absolute NDVI and Texture differences

do

Sugarcane fields at Sugarcane Field Level

find domain extrema: Sugarcane fields sub objects [level:1]: max Area in domain : Largest_Object

do

update variable: Largest_Object at Processing Level: ov_NDVI_Largest_Objects = NDVI_Object

update variable: Potential Grub Damage at Processing Level: ov_NDVI_Potential_Grub_Damage = NDVI_Object

do

update variable: Largest_Object at Processing Level: ov_LeSiSum_Largest_Objects = Mean LeSiSum_Red_Smoothed21

update variable: Low likelihood of grub damage, Potential Grub Damage at Processing Level: ov_LeSiSum_Potential_Grub_Damage = Mean LeSiSum_Red_Smoothed21

Finding NDVI Difference to Largest Healthy Sugarcane Object (*)

on Processing Map Sugarcane fields at Sugarcane Field Level

update variable: Largest_Object sub objects [level:1]: v_temp_NDVI_largest_object = [ov_NDVI_Largest_Objects]

Potential Grub Damage sub objects [level:1]: do

update variable: v_NDVI_difference = [v_temp_NDVI_largest_object]-[ov_NDVI_Potential_Grub_Damage]

assign class: if with v_NDVI_difference > 0.03 : Low likelihood of grub damage

Finding LeSiSum Difference to Largest Healthy Sugarcane Object (*)

on Processing Map Sugarcane fields at Sugarcane Field Level

update variable: Largest_Object sub objects [level:1]: v_temp_LeSisum_largest_object = [ov_LeSiSum_Largest_Objects]

Low likelihood of grub damage, Potential Grub Damage sub objects [level:1]: do

update variable: v_LeSiSum_difference = [ov_LeSiSum_Potential_Grub_Damage]-[v_temp_LeSisum_largest_object]

assign class: if Low likelihood of grub damage with v_LeSiSum_difference > 1 : Likely grubdamage

assign class: if Potential Grub Damage with v_LeSiSum_difference > 1.5 and v_NDVI_difference > 0.02 : Likely grubdamage

assign class: if Low likelihood of grub damage with v_LeSiSum_difference > 1 and v_NDVI_difference > 0.06 : Likely grubdamage

assign class: if Potential Grub Damage with v_LeSiSum_difference > 1.5 : Low likelihood of grub damage

Cleaning up

assign class: Low likelihood of grub damage with Rel. border to Likely grubdamage > 0.2 at Processing Level: Likely grubdamage

assign class: Potential Grub Damage with Rel. border to Low likelihood of grub damage > 0.2 at Processing Level: Low likelihood of grub damage

assign class: Potential Grub Damage at Processing Level: Sugarcane fields

find enclosed by class: Likely grubdamage at Processing Level: enclosed by Low likelihood of grub damage: Low likelihood of grub damage +

find enclosed by class: Low likelihood of grub damage, Sugarcane fields at Processing Level: enclosed by Likely grubdamage: Likely grubdamage +

merge region: Likely grubdamage at Processing Level: merge region

assign class: Likely grubdamage with Area < 150 Pxl at Processing Level: Sugarcane fields

assign class: Likely grubdamage with Area < 250 Pxl and Distance to Likely grubdamage > 70 Pxl at Processing Level: Sugarcane fields

[delete image object level: delete 'Sugarcane Field Level']

merge region: Likely grubdamage at Processing Level: merge region

assign class: on Processing Map Largest_Object at Processing Level: Sugarcane fields

merge region: on Processing Map Sugarcane fields at Processing Level: merge region

assign class: Low likelihood of grub damage with Area <= 400 Pxl at Processing Level: Sugarcane fields

Three Grub Damage Classes

compute statistical value: Likely grubdamage at Processing Level: Quantile_50%_NDVI_Likely_Grubdamage = quantile[50](Mean NDVI)

compute statistical value: Likely grubdamage at Processing Level: Quantile_50%_LeSiSum_Red_Smoothed21_Likely_Grubdamage = quantile[50](Mean LeSiSum_Red_Smoothed21)

assign class: Likely grubdamage with Mean NDVI < Quantile_50%_NDVI_Likely_Grubdamage and Mean LeSiSum_Red_Smoothed21 < Quantile_50%_LeSiSum_Red_Smoothed21_Likely_Grubdamage at Processing Level: Medium Likelihood of Grub Damage

Prepare to Export Shapefile

[assign class: on Processing Map Sugarcane fields at Processing Level: unclassified]

merge region: on main Low likelihood of grub damage at Processing Level: merge region

synchronize map: at Processing Level: synchronize map 'main'

[export vector layer: on main Likely grubdamage, Low likelihood of grub damage, Sugarcane fields at Processing Level: export object shapes to Mackay2014_v1]

Risk Map

Large Damaged Areas

copy image object level: on Processing Map at Processing Level: copy creating 'Risk Level' above

delete image object level: on Processing Map : delete 'Sugarcane Field Level'

assign class: on Processing Map Likely grubdamage at Risk Level: Very High Risk

pixel-based object resizing: all 50x: on Processing Map Very High Risk with Area > 800 Pxl at Risk Level: coat with High Risk into Low likelihood of grub damage, Medium Likelihood of Grub Damage, Sugarcane fields, unclassified

pixel-based object resizing: all 30x: on Processing Map High Risk at Risk Level: coat with Moderate Risk into Low likelihood of grub damage, Medium Likelihood of Grub Damage, Sugarcane fields, unclassified

pixel-based object resizing: all 20x: on Processing Map Moderate Risk at Risk Level: coat with Low Risk into Low likelihood of grub damage, Medium Likelihood of Grub Damage, Sugarcane fields, unclassified

Medium Damaged Areas

pixel-based object resizing: all 30x: on Processing Map Very High Risk with Area < 800 Pxl and Area > 400 Pxl at Risk Level: coat with High Risk 2 into High Risk, Low likelihood of grub damage, Low Risk, Medium Likelihood of Grub Damage, Moderate Risk, Sugarcane fields, unclassified

pixel-based object resizing: all 20x: on Processing Map High Risk 2 at Risk Level: coat with Moderate Risk 2 into Low likelihood of grub damage, Low Risk, Medium Likelihood of Grub Damage, Moderate Risk, Sugarcane fields, unclassified

pixel-based object resizing: all 20x: on Processing Map Moderate Risk 2 at Risk Level: coat with Low Risk 2 into Low likelihood of grub damage, Low Risk, Medium Likelihood of Grub Damage, Sugarcane fields, unclassified

Small Damaged Areas

pixel-based object resizing: all 10x: on Processing Map Very High Risk with Area > 100 Pxl and Area < 400 Pxl at Risk Level: coat with High Risk 3 into High Risk 2, High Risk, Low likelihood of grub damage, Low Risk 2, Low Risk, Medium Likelihood of Grub Damage, Moderate Risk 2, Moderate Risk, Sugarcane fields, unclassified

pixel-based object resizing: all 20x: on Processing Map High Risk 3 at Risk Level: coat with Moderate Risk 3 into Low likelihood of grub damage, Low Risk 2, Low Risk, Medium Likelihood of Grub Damage, Moderate Risk 2, Moderate Risk, Sugarcane fields, unclassified

pixel-based object resizing: all 20x: on Processing Map Moderate Risk 3 at Risk Level: coat with Low Risk 3 into Low likelihood of grub damage, Low Risk 2, Low Risk, Medium Likelihood of Grub Damage, Sugarcane fields, unclassified

Very Small Areas

assign class: on Processing Map Very High Risk with Area < 100 Pxl at Risk Level: On Watch

do

assign class: on Processing Map Low likelihood of grub damage, Medium Likelihood of Grub Damage at Risk Level: Low Risk

assign class: on Processing Map High Risk 2, High Risk 3 at Risk Level: High Risk

assign class: on Processing Map Moderate Risk 2, Moderate Risk 3 at Risk Level: Moderate Risk

assign class: on Processing Map Low Risk 2, Low Risk 3 at Risk Level: Low Risk

chessboard segmentation: on Processing Map High Risk, Low Risk, Moderate Risk with Existence of sub objects unclassified (1) = 1 at Risk Level: chess board: 1

assign class: on Processing Map High Risk, Low Risk, Moderate Risk with Existence of sub objects unclassified (1) = 1 at Risk Level: unclassified

merge region: on Processing Map High Risk at Risk Level: merge region

merge region: on Processing Map Low Risk at Risk Level: merge region

merge region: on Processing Map Moderate Risk at Risk Level: merge region

merge region: on Processing Map unclassified at Risk Level: merge region

merge region: on Processing Map Sugarcane fields at Processing Level: merge region

merge region: on Processing Map Likely grubdamage at Processing Level: merge region

merge region: on Processing Map Medium Likelihood of Grub Damage at Processing Level: merge region

merge region: on Processing Map Low likelihood of grub damage at Processing Level: merge region

merge region: on Processing Map unclassified at Processing Level: merge region

copy image object level: on main at Processing Level: copy creating 'Risk Level' above

synchronize map: on Processing Map at Risk Level: synchronize map 'main'

assign class: on Processing Map Fallow, Sugarcane fields at Risk Level: unclassified

Risk Map 2

assign class: on Processing Map Likely grubdamage, Medium Likelihood of Grub Damage at Processing Level: Likely grubdamage

merge region: on Processing Map Likely grubdamage at Processing Level: merge region

on Processing Map

on Processing Map Sugarcane fields at Sugarcane Field Level

find domain extrema: Likely grubdamage sub objects [level:1]: max Area in domain : Largest_Object

First Largest Object

update variable: on Processing Map Sugarcane fields at Sugarcane Field Level: ov Area of Individual Sugar Cane Fields = Area

on Processing Map Sugarcane fields at Sugarcane Field Level

update variable: Largest_Object sub objects [level:1]: Area of Grub Danamage (Medium and High Likelihood) = Area

update variable: ov Proportion of Grub Damage per Sugar Cane Field = [Area of Grub Danamage (Medium and High Likelihood)]\[ov Area of Individual Sugar Cane Fields]

on Processing Map

on Processing Map Sugarcane fields at Sugarcane Field Level
        find domain extrema: Likely grubdamage sub objects [level:1]: max Area in domain :
Largest_Object2
        Second Largest Object
        on Processing Map Sugarcane fields at Sugarcane Field Level
                update variable: Largest_Object2 sub objects [level:1]: Area2 of Grub Danamage
(Medium and High Likelihood) = Area
                update variable: ov Proportion2 of Grub Damage per Sugar Cane Field = [Area2 of
Grub Danamage (Medium and High Likelihood)]\[ov Area of Individual Sugar Cane Fields]
        on Processing Map
        on Processing Map Sugarcane fields at Sugarcane Field Level
                find domain extrema: Likely grubdamage sub objects [level:1]: max Area in domain :
Largest_Object3
        Third Largest Object
        on Processing Map Sugarcane fields at Sugarcane Field Level
                update variable: Largest_Object3 sub objects [level:1]: Area3 of Grub Danamage
(Medium and High Likelihood) = Area
                update variable: ov Proportion3 of Grub Damage per Sugar Cane Field = [Area3 of
Grub Danamage (Medium and High Likelihood)]\[ov Area of Individual Sugar Cane Fields]
        on Processing Map
        on Processing Map Sugarcane fields at Sugarcane Field Level
                find domain extrema: Likely grubdamage sub objects [level:1]: max Area in domain :
Largest_Object4
        Fourth Largest Object
        on Processing Map Sugarcane fields at Sugarcane Field Level
                update variable: Largest_Object4 sub objects [level:1]: Area4 of Grub Danamage
(Medium and High Likelihood) = Area
                update variable: ov Proportion4 of Grub Damage per Sugar Cane Field = [Area4 of
Grub Danamage (Medium and High Likelihood)]\[ov Area of Individual Sugar Cane Fields]
        on Processing Map
        on Processing Map Sugarcane fields at Sugarcane Field Level
                find domain extrema: Likely grubdamage sub objects [level:1]: max Area in domain :
Largest_Object5
        Fourth Largest Object
        on Processing Map Sugarcane fields at Sugarcane Field Level
                update variable: Largest_Object5 sub objects [level:1]: Area5 of Grub Danamage
(Medium and High Likelihood) = Area
                update variable: ov Proportion5 of Grub Damage per Sugar Cane Field = [Area5 of
Grub Danamage (Medium and High Likelihood)]\[ov Area of Individual Sugar Cane Fields]
        Total Proportion of Grub Damage
        update variable: on Processing Map at Sugarcane Field Level: Total = [ov Proportion of
Grub Damage per Sugar Cane Field]+[ov Proportion2 of Grub Damage per Sugar Cane Field]+[ov
Proportion3 of Grub Damage per Sugar Cane Field]+[ov Proportion4 of Grub Damage per Sugar Cane
Field]+[ov Proportion5 of Grub Damage per Sugar Cane Field]
        Classification of Risk Based on Area Affected by Grub Damage
        assign class: Sugarcane fields with Total >= 0.2 at Sugarcane Field Level: Very High
Risk
        assign class: Sugarcane fields with Total >= 0.15 at Sugarcane Field Level: High Risk
        assign class: Sugarcane fields with Total >= 0.1 at Sugarcane Field Level: Moderate
Risk
        assign class: Sugarcane fields with Total >= 0.05 at Sugarcane Field Level: Low Risk
        assign class: Sugarcane fields with Total < 0.05 at Sugarcane Field Level: No Risk
        assign class: Non-Siugarcane Fields at Sugarcane Field Level: unclassified
        assign class: Fallow at Sugarcane Field Level: unclassified

Process: OnStiched:
  OnStiched
    delete scenes: delete tiles
    Export as shapefile
        export vector layer: on main Likely grubdamage, Low likelihood of grub damage, Medium
Likelihood of Grub Damage at Processing Level: export object shapes to Mackay_May26_2013_v1

export vector layer: on main High Risk, Low Risk, Moderate Risk, No Risk, Very High Risk at Risk Level: export object shapes to Mackay_May26_2013_Risk1

export vector layer: on main High Risk, Low Risk, Moderate Risk, No Risk, Very High Risk at Sugarcane Field Level: export object shapes to Mackay_May26_2013_Risk1002

[export vector layer: on main High Risk, Low Risk, Moderate Risk, Very High Risk at Risk Level: export object shapes to Mackay_May26_2013_Risk_v1]

Customized Algorithms:

Multiple-Conditions-Based Fusion

set rule set options: set rule set options

image object fusion: loop: from calling process (domain definition): all best Classification value of Similarity > 0

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Appendix 6 - Canegrowers article

Grub monitoring

Contributed by Dr Nadar Sallam

Sugar Research Australia (SRA), in conjunction with Mulgrave Productivity Service, have been engaged in regional grub monitoring for more than 10 years. Grub monitoring provides important information on grub dynamics in nature and helps growers make well informed management decisions. Monitoring work involves digging up 20 cane plants from the four corners and the centre of several selected paddocks each year. These paddocks are targeted for monitoring because of their known history of moderate – high grub infestations. Growers are then requested to give information on their insecticide treatment history in each paddock. Results from this work showed that grub damage decreases significantly following extensive insecticide treatment on a regional level, but then it tends to re-appear if insecticide treatment is neglected. Hence, canegrub monitoring enables growers to better adjust their management program in response to grub populations in the region. Currently, SRA is engaged in Satellite Imagery work which enables the detection of early grub signs in the region, without need for a lot of digging. This tool should provide good information in the future if it were to be widely adopted by the industry.

If you wish to learn more about this and other pressing industry issues, then you may wish to attend the upcoming growers workshop which will take place at the Rambler, Gordonvale on Thursday the 26th of September. The workshop aims at updating growers on the latest canegrub monitoring results, Reef Rescue and Six Easy Steps programs, as well as the latest on Yellow Canopy Syndrome and other relevant industry issues. Growers are encouraged to participate in this workshop, especially when latest canegrub monitoring results indicate that grub damage is widespread in Mulgrave this year. Even though the detected damage levels are generally low, it is important that growers are actively engaged in another intensive round of grub management to avoid any potential out breaks.

Below is the proposed workshop agenda.

Thursday 26 September – the Rambler, Gordonvale

7:15 – 8:00 am   Breakfast and welcome note
8:00 – 8:30 am   Update on grub situation and Biosecurity
                 Nader Sallam)
8:30 – 9:00 am   Update on reef rescue and SES (David Calcino)
9:00 – 9:30 am   Update on YCS and relevant industry issues
                 (Andrew Ward)
See you there!

CANEGROWERS

Caring for our land. Caring for our reef.

Appendix 7 - SRA e-newsletter

Mass production of the Adelina disease to better manage greyback canegrubs

Key Focus

Pest, disease and weed management

Project code

2011/356

Timeframe

July 2013 - June 2016

Investment

$250,541.00

Collaborators

Sugar Research Australia

The research project ⌄

This project investigates the possibility of producing the Adelina pathogen in the laboratory.

Two methods are currently being trialled to achieve this. Conventional laboratory breeding: by collecting greyback adult beetles and allowing them to breed in the laboratory. Young larvae are then infected by the Adelina pathogen. The second method is via cell culture breeding: where Adelina oocysts are introduced to a live cell culture.

What we are doing ⌄

So far we managed to conventionally breed the Adelina pathogen in the laboratory by infecting several second instar greyback canegrub larvae. However, this method is fairly cumbersome and time consuming. We are still trying to breed the pathogen in the live cell culture, however to date the cell line does not support full completion of the pathogen's life cycle, and more work is still needed to achieve this. We are currently modifying our methodology to enhance pathogen's development in the cell line.

Remote sensing to implement an effective pest management strategy for canegrubs

Key Focus

Pest, disease and weed management

Project code

2011/342

Timeframe

July 2011 - March 2015

Investment

$499,809.00

Collaborators

Sugar Research Australia
The University of Queensland
University of New England

The research project ⌄

Remote sensing has been used in other agricultural and forestry systems to detect pest infestations over large areas.

This SRA-led project has been funded to develop a remote-sensing system that can identify early signs of canegrub infestations; develop a web-based system to deliver early-warning information; facilitate outputs of concurrent projects on risk assessment, cane beetle behaviour and predictive modelling

What we are doing ⌄

Each year, through the length of the project, high resolution satellite images were obtained and analysed to detect canegrub infestations and distinguish them from other disorders. Web-based infestation maps were developed and provided to collaborating growers and productivity services groups to obtain feedback, demonstrate the value of the system and encourage its adoption.

The University of Queensland joined SRA and DAFF Queensland during the 2012-2013 year as a partner in the project to develop algorithms for damage detection using the remote-sensing system. During 2013-2014 the project used the refined methodology to correlate satellite imagery and risk maps with actual locations of canegrub damage in the 2013 calendar year, as well as re-examining images and known damage from 2012. A third cycle of image capture and ground truthing commenced in early 2014. Ultimately, reliability of the refined detection system will be assessed across the three years of image capture and the different districts.