Australian Government
Cotton Research and Development Corporation

FINAL REPORT 2013

Executive Summary

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

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Survey for feral cotton volunteers in landscapes associated with cotton production & transport

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Executive summary

A survey was conducted to ascertain the presence of feral cotton plants in off-farm drainage areas and along roadsides associated with cotton production and transport throughout Queensland and parts of northern NSW. The establishment and presence of these plants is the direct result of the movement of cotton seed from overland flow associated with irrigation runoff into common drainage lines or module road freight. Feral plants were characterised and recorded as either seasonal (6 months or less, e.g. summer volunteers) or perennial (survival of 12 or more months) and geotagged for future reference. Perennial plants were sub-sampled to determine disease status, transgenic heritage, and pest insect presence. Survey findings included:

- The overall incidence of feral plants on Queensland's roadways is low. Densities were highest adjacent to cotton farms and in close proximity to ginning facilities.
- Cotton spilt during module cartage is the primary source for feral cotton plants but only a very low proportion of spilt seed successfully germinates and establishes a plant. Many roadside plants were associated with structures such as culverts and sign posts that provide a more favourable micro-climate for plant establishment.
- The disturbance of roadside areas during road construction or maintenance can both greatly increase the recruitment rate (due to incorporation of seed cotton) and destroy feral cotton plants on roadways.
- Drainage channels associated with the central Queensland and St George irrigation areas had a high incidence of volunteer plants, typically adjacent to cotton cropping areas.
- All feral cotton plants tested positive for Bt and/or RR traits
- Of the perennial plants sampled nearly half were found to be positive for Cotton Bunchy Top Disease (CBTD). All positive samples (with one exception in the Dawson Valley) occurred in close proximity to cotton fields.
- Pest insects were relatively infrequent, although this may be due to the cooler than average winter. Nearly all roadside feral plants north of Clermont hosted the mealybug *Phenacoccus solenopsis*.
- Many of the feral plants geo-tagged in the pre-season survey had perished (died or could not be accounted for) by early autumn. Losses were due to climatic factors, competition with grasses, roadside mowing and spraying, roadside burning, and channel spraying.

Maps of feral cotton incidence have been created and are available on request.

The majority of feral cotton plants would appear to be directly associated with nearby farming operations. The incidence of cotton plants at distances of 5 km or more away from cotton farms was low despite significant cartage of cotton modules to regional gin operations. Improved

module coverage would reduce the amount of seed cotton that is lost during the early stages of transport to the gin. The high incidence of feral cotton near gins may reflect the losses of loose seed cotton from truck trailers upon exiting the gin. A more rigorous clearing of trailer decks before departing the gin should significantly reduce these populations.

Shared drainage channels had a high incidence of cotton plants. As these areas are managed by irrigation infrastructure authorities, it is recommended that cotton grower associations and Cotton Australia consider negotiating a set of formal control arrangements with the channel managers for feral cotton in these areas. The high incidence of CBTD within feral plant populations throughout each irrigation area should provide a market-based mechanism for encouraging feral plant control.

Introduction

Australian cotton production is dependent on effective Integrated Pest Management (IPM) programs that are strongly underpinned by transgenic technology and a strong emphasis on farm hygiene. A critical component of effective on-farm hygiene involves the removal of all cotton plants between cropping seasons as this eliminates plant hosts for aphids, whitefly, mealybugs, and the aphid vectored Cotton Bunchy Top Disease (CBTD). The elimination of volunteer plants on-farm between seasons limits the opportunity of these pests and diseases, as well as pesticide resistant pest strains, to persist locally on volunteer plants (often referred to as 'green bridges').

The long term viability of *Bacillus thurengiensis* (Bt)-based transgenic technologies is also dependent on a production break and resultant period of non-exposure for *Helicoverpa* spp. As such the Resistance Management Plan to which all growers agree to conform as part of their Technology User Agreement (TUA) with Monsanto specifically states that all crop residues must be destroyed at the end of each cropping season and that volunteers are to be controlled.

Adherence to farm hygiene principles is typically high throughout the Australian cotton industry. However, landscapes adjacent to cotton farms (such as roadways and irrigation drainage causeways) can harbour transgenic cotton plants. These areas fall outside of usual TUA processes, and these plants have the capacity to host important pests and diseases and constitute an additional exposure risk for *Helicoverpa* spp. to Bt toxins.

The presence of Roundup Ready™ feral plants on roadsides has presented difficulties for local authorities when implementing roadside weed control programs that are typically reliant on the use of glyphosate. Local government agents have previously raised concerns with the Central Highlands Cotton Growers Association regarding the incidence of feral cotton plants growing on roadsides adjacent to guide posts and difficulties with control. In response to this, the local CGA put in place better practices to limit the spillage of seed cotton from modules during cartage.

A common perception within the cotton industry is that the incidence of feral plants is greater in warmer production regions such as central Queensland than on the Darling Downs, however quantitative data on the extent of feral plants and their associated pests and diseases is unknown.

The last five years have seen a number of new or changing pest management issues for the cotton industry. Increases in the resistance frequencies in both *Helicoverpa* spp. to Bt toxins, the increased incidence of CBTD, and outbreaks of mealybugs (*Phenacoccus solenopsis*) may have potential interactions with feral plants within broader agro-landscapes. However, without data regarding feral plant abundance it is difficult to ascertain these prospective relationships. The movement between feral plants and cotton crops by overwintering pests such as aphids is also unknown.

From a biosecurity perspective, a knowledge of the abundance and likely whereabouts of feral plants in the broader landscape would be critically important should a new pest or disease arise in a particular region. For example, boll weevil *(Anthonomus grandis)* requires cotton bolls for reproduction and the presence of feral plants along roadways adjoining production regions would help enable the spread of this pest from region to region. Similarly, should an outbreak of a virus disease such as Cotton Leaf Curl Disease occur, feral plants may serve as a bridge between regions for disease spread. The ability to rapidly survey feral plants may also provide an additional means of determining the spread of an exotic pest or disease and enable area freedoms to be verified with greater confidence.

This report presents the findings of an extensive survey of Queensland's roads (local and major transport corridors) and the drainage causeways that service the developed irrigation districts of

Emerald, Theodore, and St George. The characteristics of observed volunteers such as persistence, transgenic heritage, and presence of pests and disease were assessed. A specific survey was also undertaken of the roadway between Emerald and Atherton for comparison with an earlier survey conducted by Farrell and Roberts (2002). The 2002 survey represents one of the few assessments of volunteer feral cotton undertaken in Queensland, and modules of cotton have been transported through part of this corridor from the Burdekin and Belyando regions to gins in Emerald since 2007. Comparing the north Queensland surveys provided an opportunity to see whether the transportation of modules (as opposed to just cotton seed) had resulted in changes to the densities of feral cotton over approximately 600 km of roadway.

A subsequent end of cropping season survey was also conducted in autumn in the traditional cotton growing areas to measure changes within existing feral plant populations in terms of recruitment over the summer season.

The production of detailed maps based on global positioning systems will allow other researchers to visit areas with high feral cotton plant densities. These maps could be a useful resource, particularly for plant protection specialists investigating the presence or absence of pests and diseases hosted on cotton plants, and could be used to assist in determining area freedoms if a new pest or disease is located in a particular cotton production region.

Methodology

An extensive survey was undertaken of Queensland's roadsides together with the drainage causeways within the primary irrigation districts of Central and South West Queensland. Some roadsides in Northern NSW were also surveyed during this study as opportunities arose with alternate project travel.

This survey had the following aims:

1. Ascertain the abundance of feral cotton plants within Queensland's agricultural landscapes that are associated with the production or transport of cotton.
2. Characterise feral plants in terms of establishment (perennial or seasonal) and whether plants occurred individually or in groups.
3. Record the immediate environment where feral plants were growing e.g. roadside, culverts, drains, farm boundaries.
4. Ascertain the transgenic heritage of perennial feral cotton plants, the presence of pest insects such as cotton aphid and mealybugs, and disease status for CBTD.
5. Record each feral plant location using GPS, and record related information, with the objective of creating maps that can be used by other researchers.
6. Conduct the survey twice (pre-season and end of season) to gain an indication of the likelihood of plants acting as green bridges for pests and diseases and provide an insight into potential patterns of feral plant recruitment over time.

Survey protocol

The survey was conducted in stages during the 2012/13 season. It targeted all Queensland cotton growing regions and any roadways where one could reasonably expect feral cotton to occur due to spilt seed cotton from module cartage en-route to ginning facilities or cottonseed transported for stockfeed. Similarly, any accessible drainage causeways leading from irrigation properties in Queensland's channel fed systems were also targeted for surveying.

Each area was surveyed by vehicle with a two-person team, where the passenger visually assessed the roadside or drainage areas for feral cotton plants. In the irrigation areas with associated local roads and drainage lines this entailed travelling at a slow speed (40-80km/hr). On major highways survey speeds were increased to 60-100km/hr depending on the likelihood of locating cotton plants (the probability of finding plants on roadways where modules had been transported from farms to ginning facilities was deemed to be higher, and therefore lower speeds were used).

Plant positions were noted using GPS coordinates, and their establishment (perennial/seasonal) and density (individual/grouped) recorded.

GPS recording

The location of each feral plant was recorded using a Garmin Montana 650T hand held device. Photos for a number of sites were also taken with this device which allowed geotagging of images. Identifying information was recorded with each waypoint representing a feral plant. These descriptors are given in table 1 and examples are shown in photographs 1-6.

Table 1. Code for describing recorded feral plant waypoints

Plant growth type	Plant stand	Environment
P = Perrenial (growing for more than one summer) S = Seasonal (a plant that has only recently established within 6 months e.g. is small with limited reproductive structures and yet to survive through a winter season.	S = A single isolated plant P = 2 or more plants in close proximity (patches) (e.g. 10 m)	R = Roadside C = Culvert or cement roadside structure of some sort associated with drainage. D = Irrigation drainage causeway I = Interface environment whereby plants fall just on the edge of a property boundary but on public space eg cotton at the base of power poles beside a cotton field but closer to field than roadside. The origin of these plants is clearly from the adjacent farm.

All GPS data was downloaded into the Garmin BaseCamp program from which it could be exported to other programs. All of the GPS data and photos taken were converted to a format that allowed viewing in Google Earth as this program is freely available for other users to access the project data records.

Photo 1. A perennial plant denoted by growth and bolls that span a previous summer season.

Photo 2. A seasonal plant that has established more recently and lacks mature bolls and older growth.

Photo 3. A typical roadside type environment.

Photo 4. A roadside culvert environment.

Photo 5. A typical example of a shared drainage channel environment within an irrigation system.

Photo 6. Cotton plants growing on public space but in an environment denoted as interface as these plants clearly have originated from the farm in the background.

Sampling to determine transgenic traits and pest status

Samples were taken from feral plants encountered during the survey depending upon their environment, location, and circumstances. Only perennially growing plants that were green, had survived winter, and showed promise for continued growth into the following summer season were sampled as these plants were most likely to provide a green bridge.

Perennially growing feral plants along highways were regularly sampled to determine transgenic heritage, pest insect status and if symptoms were present a sample for CBTD taken. These plants were typically some distance from production areas and consequently served as sentinel samples for the context of the broader agricultural landscape. Within the irrigation districts where feral plants were abundant, samples were taken every 10-30 plants to get a relative measure of the presence of pest insects, bunchy top and biotech traits.

Pest insects were sampled by visually inspecting the plants for presence or absence. Cotton Bunchy Top disease was assessed by collecting a small amount of plant material into a labelled paper bag and placing it in a car fridge set to 2°C for storage until they could be sent to Murray Sharman's laboratory at the Eco-science Precinct for PCR analysis.

Sampling for Bt or Roundup Ready transgenic traits was conducted by collecting seed cotton from selected plants, and the lint removed from the seed using a small 10 saw mini-gin. The seed samples were then sent to Brett Ross at the CSD Wee Waa laboratory for testing. For each test, one half of a seed embryo was placed into a test tube and ground in extraction buffer. A Quickstix™ test strip was added for five minutes, then a visual assessment of the presence or absence of Cry1Ac, Cry2ab and RR was made. Two replicates of each seed sample were tested, and if a test result anomaly occurred a further two replicates were tested. A detailed description of this technique is available at http://www.envirologix.com/library/as046lsinsert.pdf.

Second pass survey of main cotton areas

A second survey was conducted for all cotton growing areas and adjoining transport networks at the end of the summer growing season. During this survey, only the roadways and drainage lines that had previously harboured cotton plants were re-surveyed. Particular attention was given to locations where plants had been previously located to determine whether any changes had taken place during the intervening 5-7 months. Any new plants observed were recorded and representative samples were taken for CBTD and pest insects.

Sampling for transgenic heritage was only conducted during the pre-season survey due to the abundance of seed cotton at this stage. The absence of conventional (non-transgenic) cotton found during the first surveys suggested there was minimal value in taking additional samples.

North Queensland roadside survey

A single survey was also conducted of the transport corridor between Emerald, Atherton and the Burdekin region and between Emerald and Richmond.

The survey between Emerald and Atherton and the Burdekin was conducted according to the protocol and methods described by Farrell and Roberts 2002 who surveyed the same route during 2002 as part of a study to determine cotton volunteer abundance from cotton seed that may have been spilt from road freight. At the time, cotton seed was regularly transported from the Emerald gins to dairy farmers on the Atherton Tablelands.

Since then, dairy farming has been in decline on the Tablelands with a corresponding reduction in the transport of fuzzy cotton seed. However, since 2007, cotton modules have been transported from the Burdekin to the Emerald gins as well as from the Belyando region to Emerald providing an alternate source of seed spillage that could give rise to feral plants. Using

the 2002 study as a benchmark a new survey in 2013 provided a unique opportunity to compare the potential impact of 5 seasons of commercial module transport on the frequency of roadside feral cotton. Also of interest was the ability to retrace the previous survey using the same GPS locations as survey points to see whether previously identified feral cotton plants still remained.

The north Queensland survey applied the same protocol as described by Farrell and Roberts using the previous GPS sample points recorded. The original survey aimed to cover 1% of the total distance, and sample sites had been selected at approximately 50 km intervals (exact stopping points were influenced by access and safety considerations). At each stop, 500 m of roadside was walked whilst visually searching for plants. The start and finish co-ordinates for these sample sites are given in appendix 1. The 2013 survey re-examined the Farrell and Roberts sample sites, and in addition applied the same visual scanning technique used during the surveys of southern cotton growing regions.

The road between Richmond and Emerald was also surveyed using a similar technique whereby approximately 1% of the roadway was sampled. This has been an occasional corridor for the transport of cotton modules grown during test farming on the Flinders River in 2001 and 2012, as well as a route for cartage of seed cotton for livestock usage.

All feral plants found during the NQ survey were examined for pest insects and samples were collected for CBTD testing.

Results

Track maps for all areas surveyed

An extensive survey was taken of roadways in both Queensland and northern New South Wales together with common drainage areas in the cotton irrigation areas of St George and Central Queensland. Figure 1 depicts the roadways that were surveyed during the study.

Figure 1. A total of 10,596 km of roadways and drainage access ways were surveyed during the course of the study. The majority of this route was surveyed pre and post season (exclusions were NQ, Mackenzie & Fitzroy River regions which was only surveyed once).

Figures 2-4 show the survey pathways taken in central Queensland. Main roadways were selected on the basis of the likelihood that cotton modules would have been transported from cotton production areas to ginning facilities in Emerald or Moura. Local roads that service individual cotton growing properties were also surveyed together with common drainage channels within the Sunwater managed Emerald and Theodore irrigation districts. It was not possible to survey all Sunwater drainage channels as some areas were closed off with restricted access.

Figure 2. Roadways surveyed in central Qld

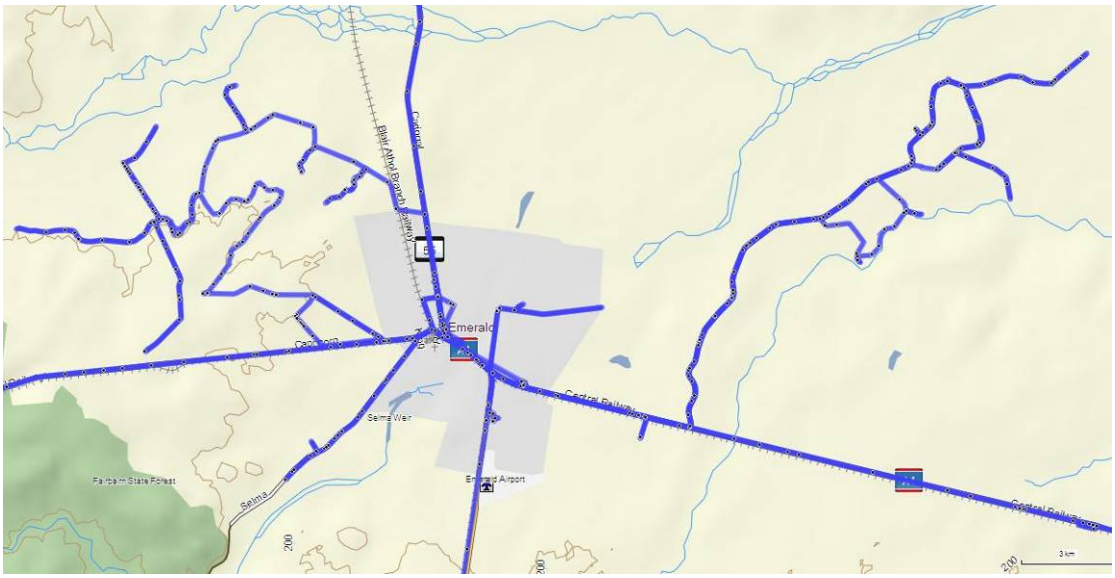


Figure 3. Survey path through the Emerald irrigation area.

Figure 4. Survey path through the Theodore irrigation area.

Figures 5 depicts the roadways that were surveyed for the Darling Downs region. The Downs survey predominantly consisted of roadways as nearly all irrigation infrastructure is privately held on-farm.

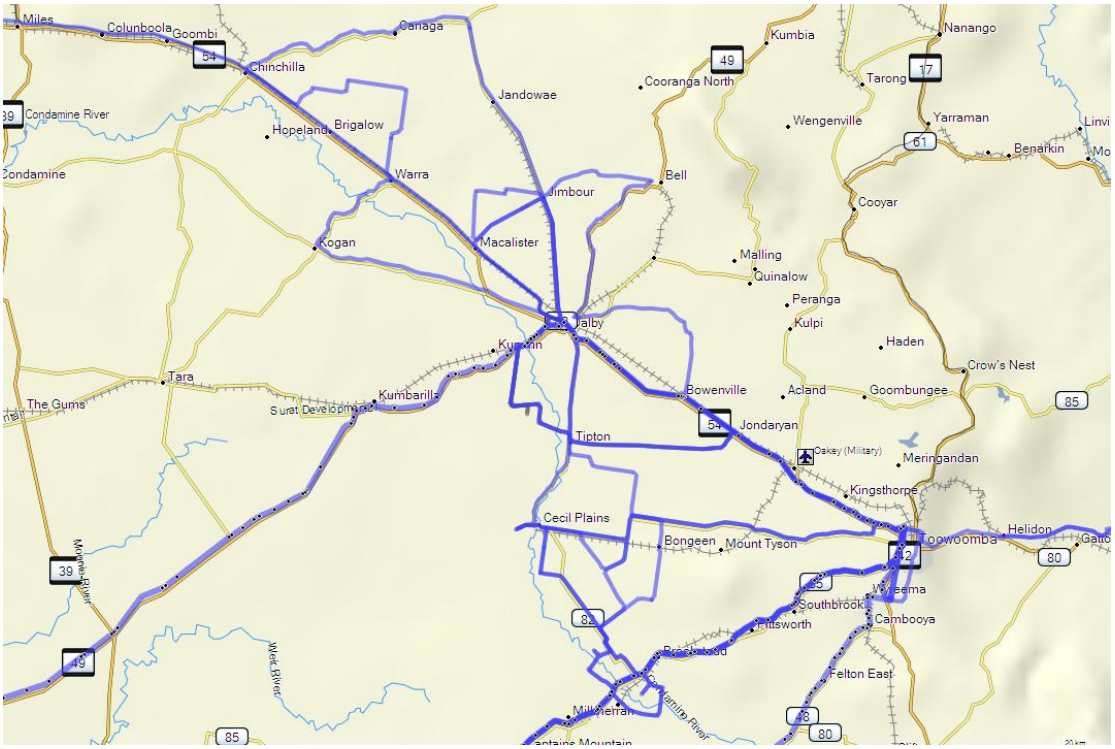


Figure 5. Survey path throughout the Darling Downs region.

Figure 6 shows the survey pathways for Queensland's southwest and border rivers production areas. Again roadways were chosen based on transport pathways to ginning facilities. Within the St George irrigation area, common drainage areas were surveyed were access was permitted. A more detailed track map for St George is given in Figure 7.

Figure 6. Roadways surveyed in the south and south west Queensland regions and Northern NSW.

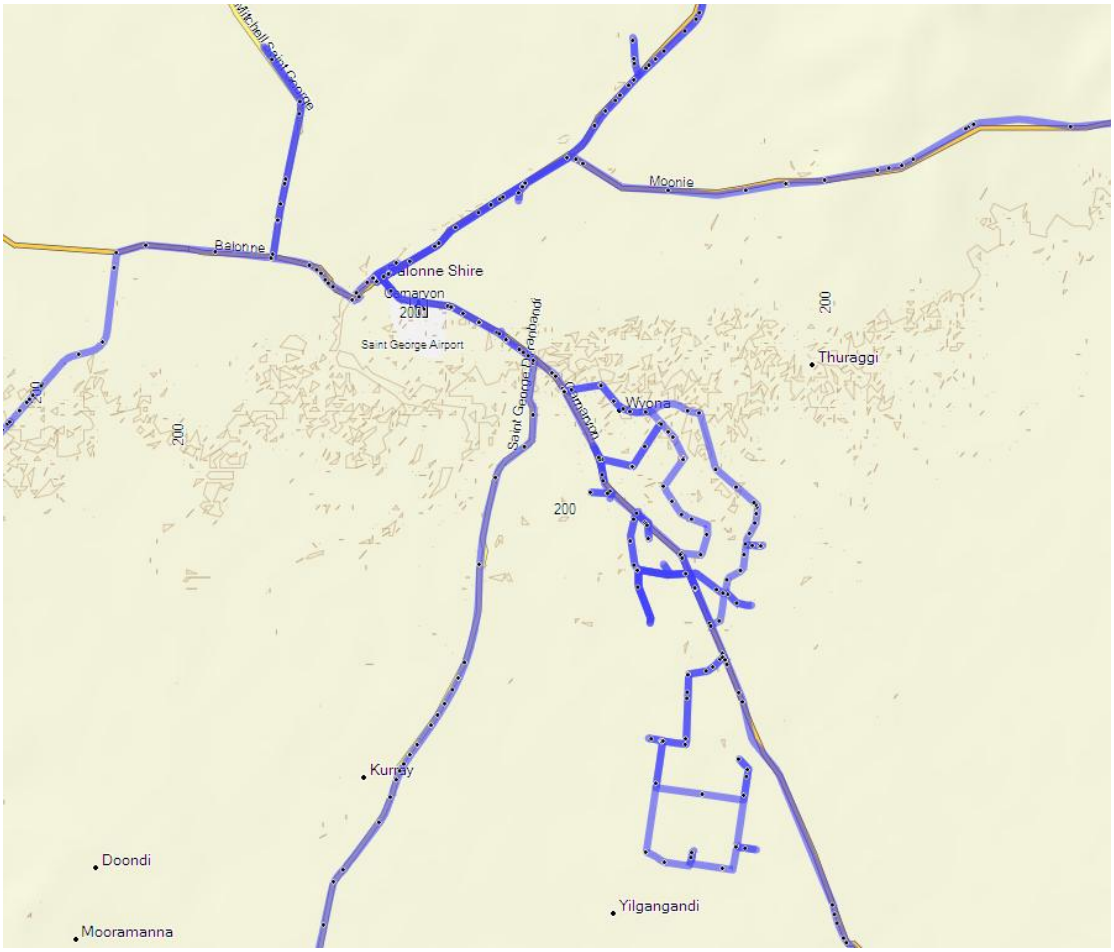


Figure 7. Survey path through the St George irrigation area.

Figure 8 details the survey conducted on major road ways in northern New South Wales. These roadways were surveyed as they had a high abundance of spilt lint from module cartage and provided a southern comparison for parts of Queensland.

Figure 8. Roadways surveyed in northern NSW.

Pre-season incidence of feral cotton within the irrigation regions

Cotton volunteers were found in each of the main cotton producing regions (CQ, Darling Downs & St George/Dirranbandi) prior to the commencement of sowing for the 2012/13 season. Feral cotton plants were found to be partly green and leafy in the CQ and St George areas (warmer regions) (Photo 7) whilst plants on the Darling Downs and Macintyre areas were leafless and either nearly dead or had small leaves or buds on the lower main stem (Photo 8). The potential of regrowth for many of these plants was questionable as they showed minimal signs of survival beyond green stem under the bark when severed.

Photo 7. Perennial plant against a culvert near St George showing typical green foliage.

Photo 8. Perennial plant on the Darling Downs that only has green foliage at the base.

Central Highlands, Dawson Callide and Mackenzie River regions

The survey of roadways and channels in the collective central Queensland region covered an approximate distance of 2071 km during which 277 locations were logged where one or more plants were recorded (Figs 9-13). For the Central Highlands, the presence of plants or patches of plants were predominantly associated with nearby cotton production fields with 93% of mapped plants located within 5 km of cotton fields either on local roads or irrigation drainage lines. The Dawson was dissimilar as 39% of mapped plants were located on the main roads connecting the Theodore and Biloela production areas and the Moura gin. The remaining plants were found to be directly adjacent to cotton fields but outside of farm boundaries.

Approximately two thirds of the feral plants logged in central Queensland were deemed to have been growing for longer than 6 months and therefore perennially. These plants were typically large, with multiple fruiting sites that had clearly grown during the previous summer season, had survived winter and were still green at the beginning of spring. The remaining plants were typically small and had no or limited fruiting structures and had been growing for less than a full summer season e.g. plants may have germinated in late summer or autumn. Some plants recorded as being seasonal were larger plants that had suffered significant stress during winter and were of questionable status regarding the ability to continue growing perennially (Fig 14a).

Over half of the feral plants logged on the Central Highlands were found to be growing in patches of two or more plants. These plant patches were predominately (73%) found in Sunwater drainage channels (Fig 14b).

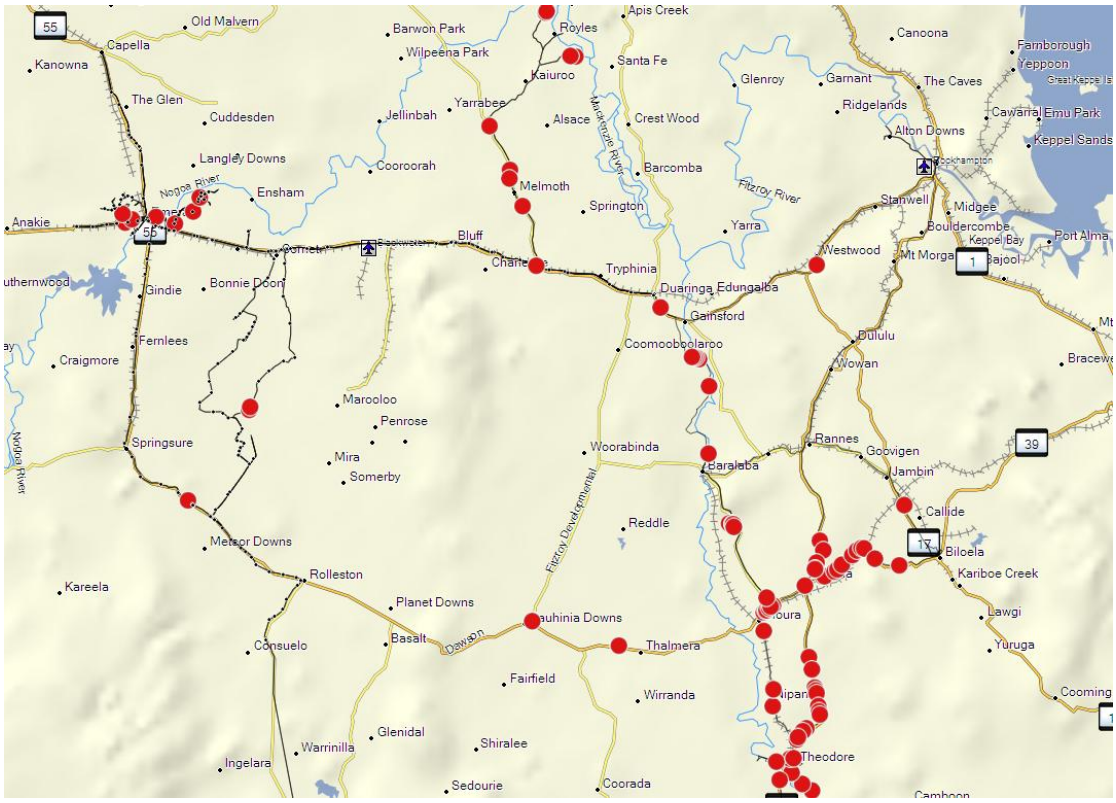


Figure 9. Feral cotton plant locations in central Queensland.

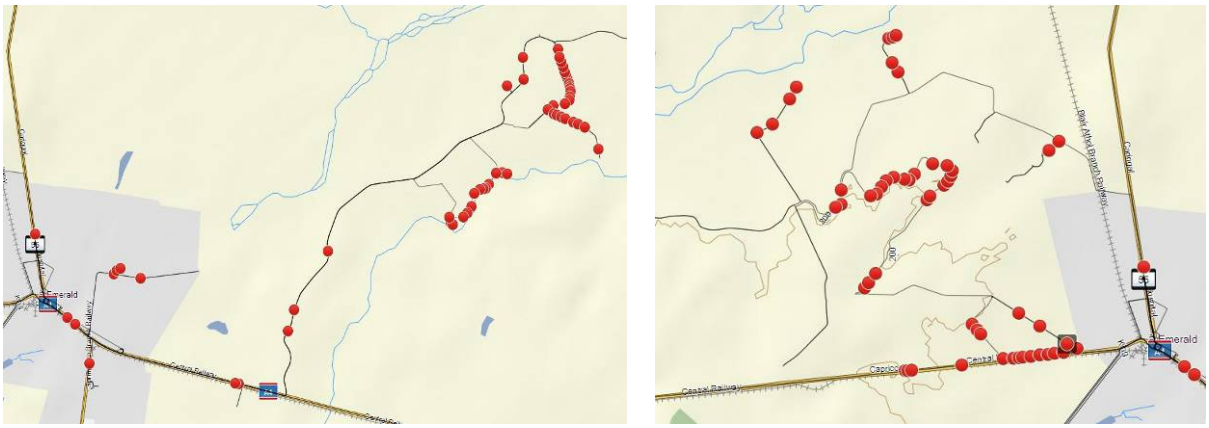


Figure 10. Feral cotton plant locations in the east (left) and west (right) sections of the Emerald irrigation area

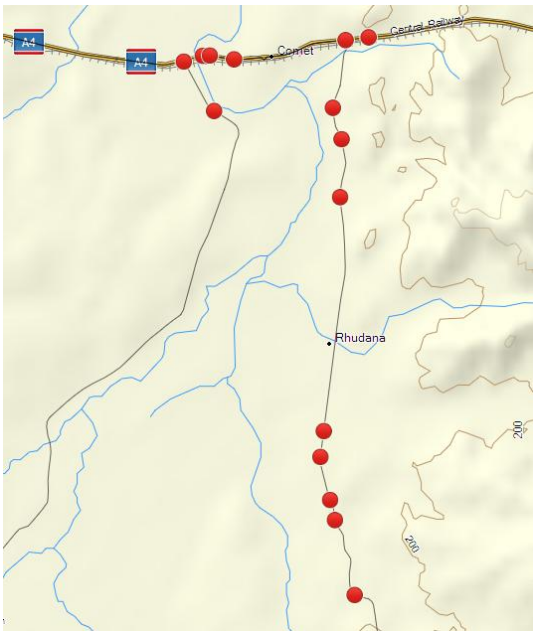


Figure 11. Feral cotton plant locations in the Comet area.

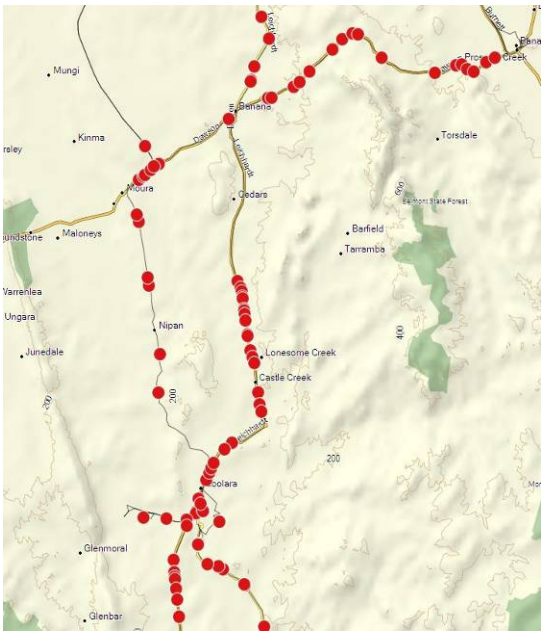


Figure 12. Feral cotton plant locations in the upper Dawson and Biloela growing areas.

Figure 13. Feral cotton plant locations in the Theodore irrigation area.

Sunwater drainage channels were the dominant habitat type (53%) for feral cotton plants for the Central Highlands. Roadsides comprised 44% of feral plants of which 16% of these (or 7% of all plants overall) occurring in roadside culverts where plants were protected from roadside slashing and in many cases weed competition (Fig 14c).

The Dawson Callide region of central Queensland was similar to the Central Highlands with two thirds of the logged plants being classified as growing perennially. However, the majority of these plants were found growing in singular isolated stands predominantly associated with roadsides (91%) (Fig 15c). The few common commonly shared drainage causeways in the Theodore irrigation area were found to be mostly free of feral plants. Any plants that had been present were badly damaged from prior applications of herbicide.

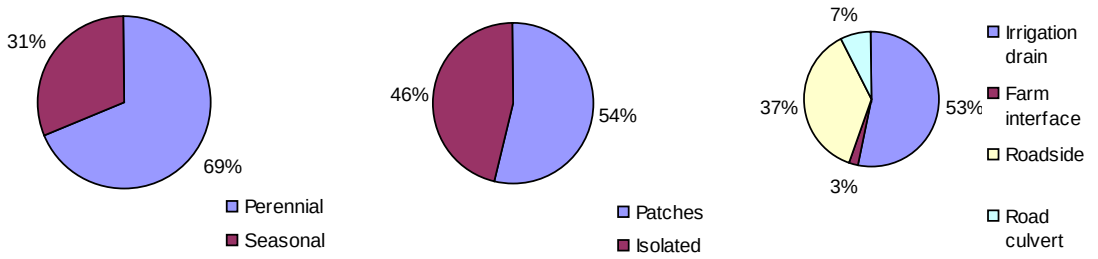


Figure 14. Descriptive data (relative percentages) for recorded feral plants in the Central Highlands. (a) longevity (perennial versus recently established seasonal plants) (b) abundance (isolated single plants versus patches of 2 or more plants) & (c) the immediate environment.

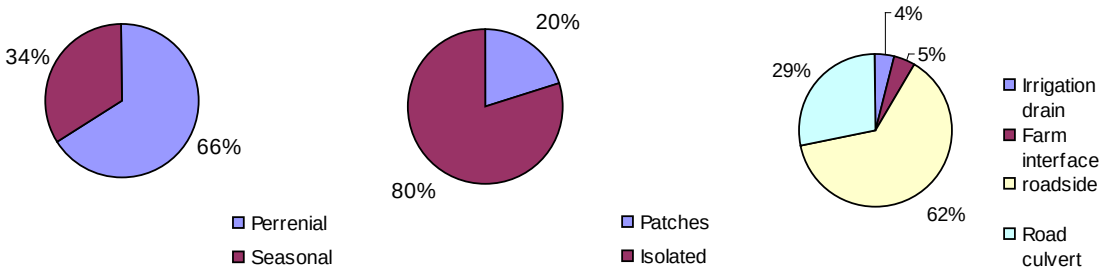


Figure 15. Descriptive data (relative percentages) for recorded feral plants in the Dawson/Callide. (a) longevity (perennial versus recently established seasonal plants) (b) abundance (isolated single plants versus patches of 2 or more plants) & (c) the immediate environment.

Photo 10. Feral cotton growing perennially within shared drainage lines was a common occurrence.

Darling Downs

The survey of the Darling Downs region covered an approximately 997 km of roadways, and 61 locations were logged where one or more plants were recorded. These plants were generally found on roadsides or directly adjacent to cotton fields in what was termed an 'interface' area.

The Darling Downs was dissimilar to central Queensland and the Balonne catchment with only 23% of logged plants growing perennially. Many of these plants were difficult to assess as they had been frosted and retained what appeared to be green buds or shoots on the lower canopy or what appeared to be live green tissue under the bark. Unlike central Queensland, a third of plants were recorded directly adjacent to cotton fields, which were the likely point of origin. The remainder were located on roadsides. No cotton plants were logged on drainage lines as these were typically all located on private property.

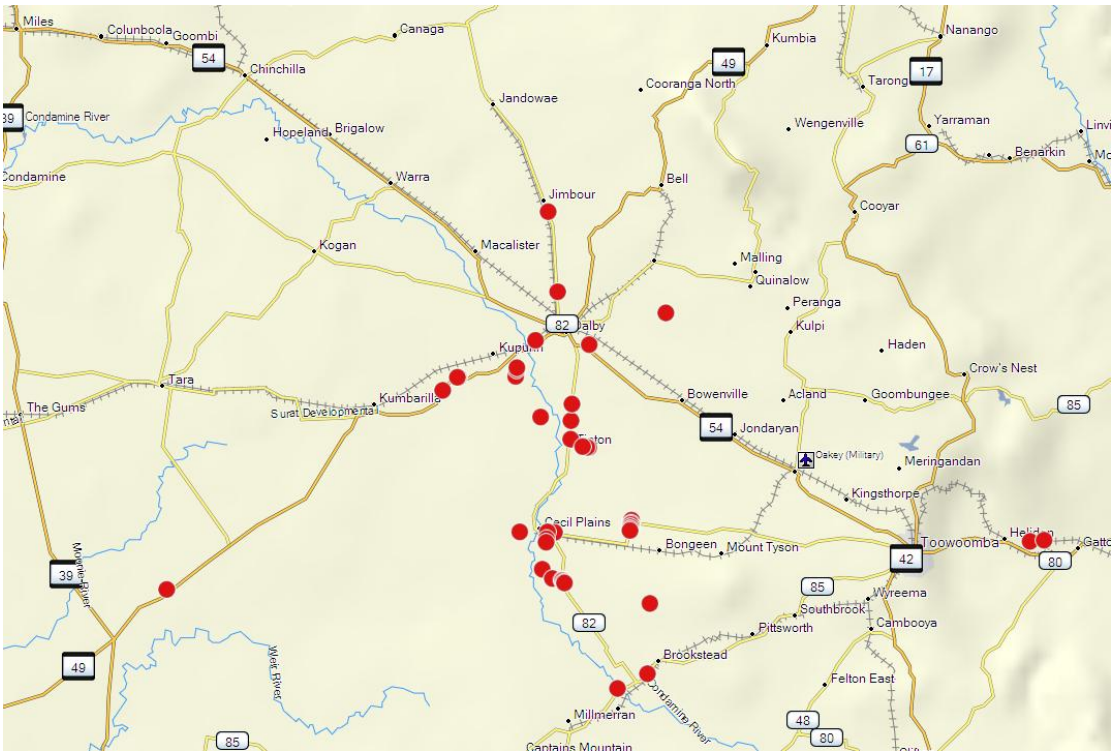


Figure 16. Feral cotton plants locations on the Darling Downs.

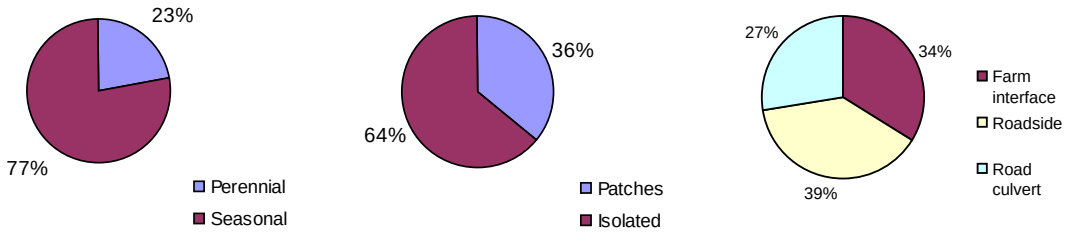


Figure 17. Descriptive data (relative percentages) for recorded feral plants in the Darling Downs region. (a) longevity (perennial versus recently established seasonal plants) (b) abundance (isolated single plants versus patches of 2 or more plants) & (c) the immediate environment.

Photo 11. Plants classed as 'farm interface' were common on the Darling Downs. These plants are just outside of this farm boundary but their origin is relatively clear.

Border Rivers and Balonne catchment

The survey of the St George, Mungindi, and Goondiwindi regions covered approximately 1332 km of roadways. One or more plants were recorded at 238 locations.

Figure 18. Location of feral cotton plants in the Border Rivers and Balonne catchment areas.

Figure 19. Moonie and Carnarvon highways leading into St George.

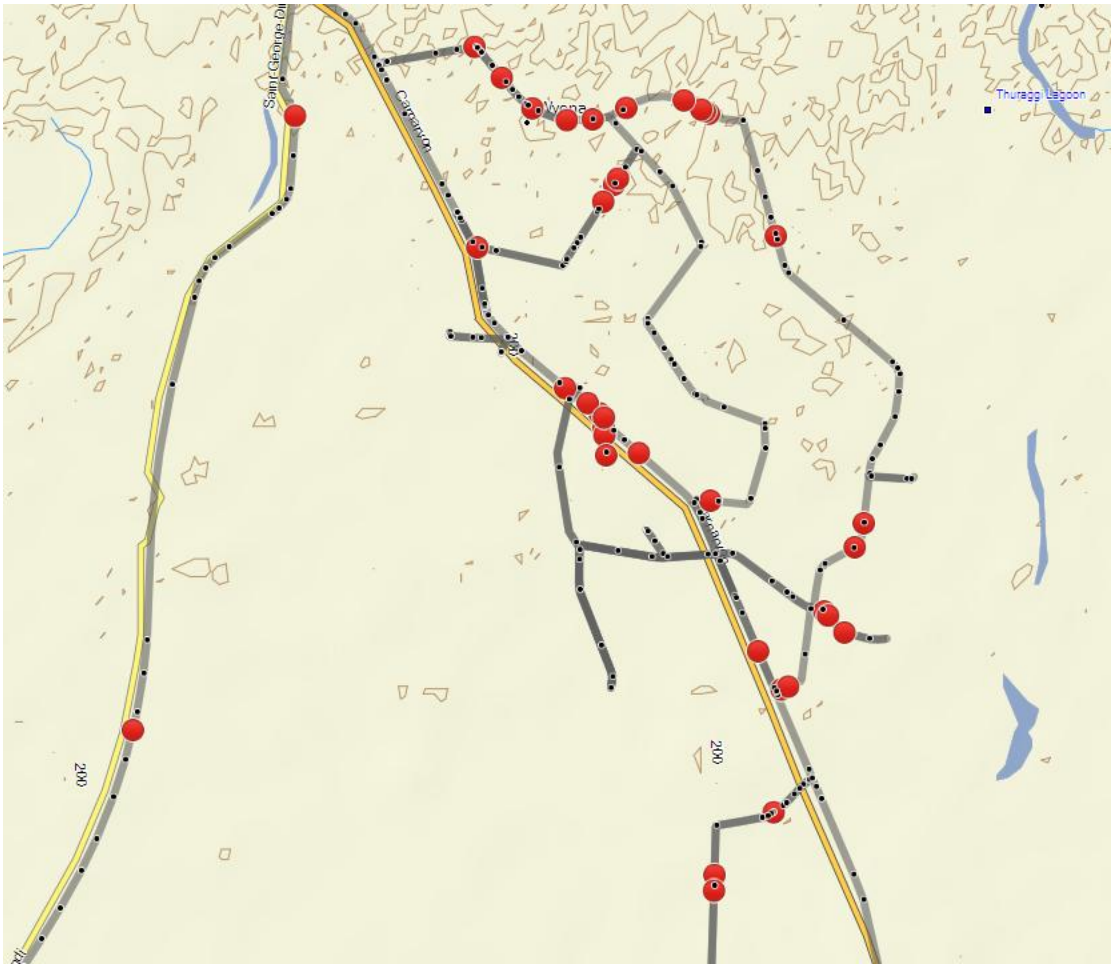


Figure 20. St George channel irrigation area.

Figure 21. Roadways south west of St George irrigation area and Dirranbandi.

This region had a very high incidence of roadside plants. accounting for over 90% of the plants found (Fig 22). Plants were very prevalent throughout local roadways in the St George irrigation area, and these were mostly observed to be growing perennially.

In the outer lying areas, many of the plants that were logged were associated with road works where soil disturbance 12 months earlier had incorporated seed and allowed germination. This also resulted in many plants being found in patches as opposed to occurring as isolated plants. An example was where a grader had cleared roadside drainage lines over large distances, and cotton could be found growing in lines along roadsides at the edges of this soil disturbance (Photo 14). Many of these plants had grown to a considerable size (16 nodes or more), had been frosted or dried off during winter, but still retained green buds or shoots on the lower half of the plant and were therefore recorded as growing perennially. However, their capacity for continued growth into the subsequent summer season was uncertain.

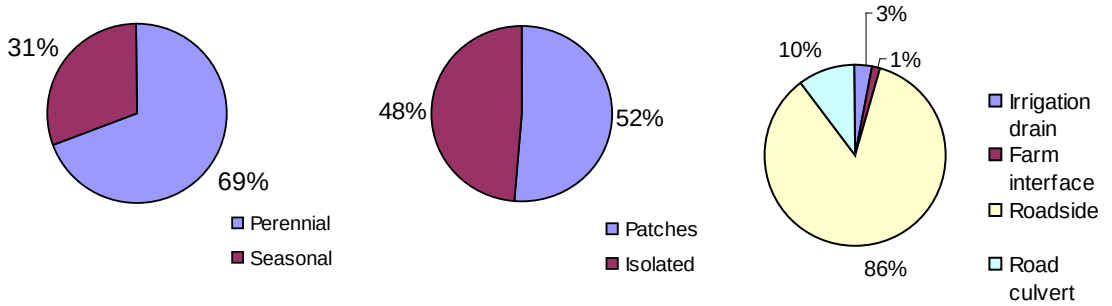


Figure 22. Descriptive data (relative percentages) for recorded feral plants in the St George, Mungindi and Border rivers regions. (a) longevity (perennial versus recently established seasonal plants) (b) abundance (isolated single plants versus patches of 2 or more plants) & (c) the immediate environment.

Photo 12. Feral cotton growing in a protected space along the Moonie Highway leading into St George. These plants were hosting aphids and CBTD at the time of sampling.

Photo 13. A typical example of feral cotton plants growing on local roadways in the St George irrigation area.

Photo 14. Feral cotton that has established due to the incorporation of seed cotton during civil construction and roadside grading.

Northern NSW

The survey of the NSW border side of Goondiwindi, Mungindi, Moree, and surrounding regions covered approximately 736 km of roadways during which 69 locations were logged where one or more plants were recorded.

The majority of plants located during this pre-season survey had been badly affected by frost during winter and many were struggling to grow back perennially.

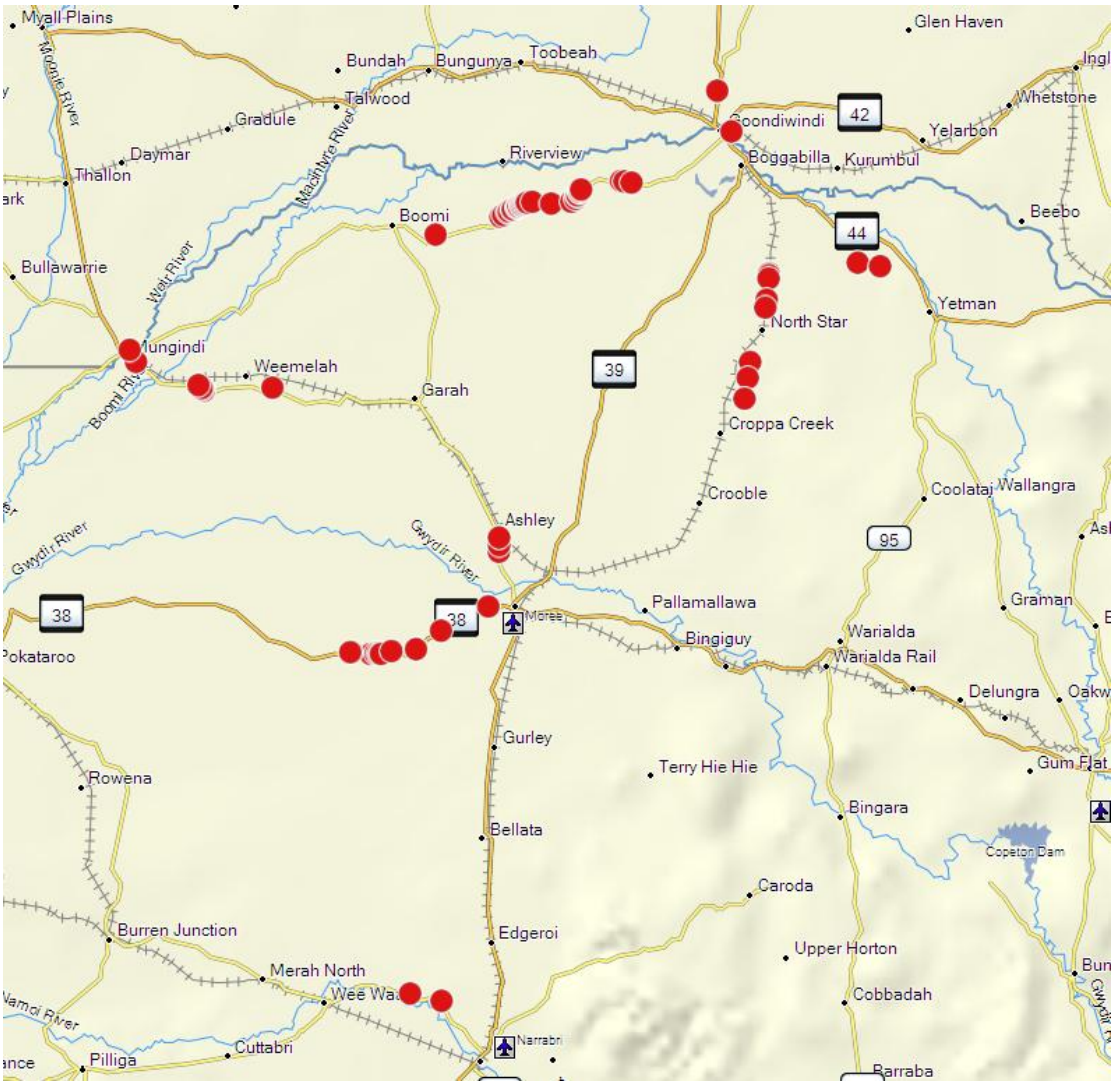


Figure 23. Location of feral cotton plants in Northern NSW pre season.

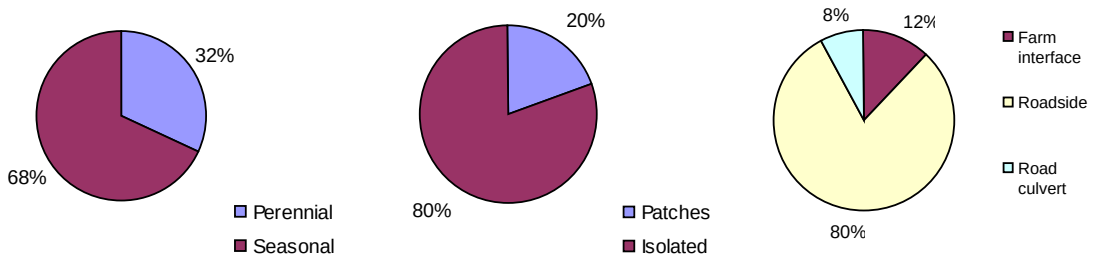


Figure 24. Descriptive data (relative percentages) for recorded feral plants in the northern NSW region. (a) longevity (perennial versus recently established seasonal plants) (b) abundance (isolated single plants versus patches of 2 or more plants) & (c) the immediate environment.

Genetic heritage

Seed cotton was collected from 76 plants that were growing perennially across all of the regions surveyed. 100% of the samples tested positive for a transgenic trait (either positive for Bt or RR or typically both). All samples that tested positive for Bt were found to contain Cry1ac and 2ab

proteins suggesting that the origin of these plants were Bollgard II. The two plants that tested negatively for Bt were found to be positive for the RR trait.

Table 2. Results from genetic testing of seed collected from feral cotton plants in each region.

Region	No Samples tested	Cry 1ac	Cry2ab	RR	Samples free of any transgenic traits
CQ	31	30/31	30/31	29/31	0/31
Darling Downs	18	17/18	17/18	18/18	0/18
St George & Qld Border Rivers	22	22/22	22/22	21/22	0/22
Northern NSW	5	5/5	5/5	4/5	0/5
Total	**76**	**97%**	**97%**	**94%**	**0%**

Pest insects

Sampling at regular intervals for pest insects confirmed a very low abundance of insects pre-season. The only pest insects recorded were cotton aphids, mealybug, and cotton stainers. On several occasions the presence of old pupal cases (mummies) provided evidence of earlier aphid infestations. Mealybugs were only found on feral plants samples in central Queensland.

Table 3. Results from examining feral plants for pest insects in each region showing region pre-season. Very few plants had active pests although evidence for previous aphid activity was found.

Region	No. sites examined	Aphids	Mealybug*	Cotton stainers	Parasitised aphids
CQ	55	1/55	5/55	7/55	4/55
Darling Downs	24	0/24	0/24	0/24	2/24
St George & Qld Border Rivers	32	3/32	0/32	8/32	6/32
Northern NSW	11	0/11	0/11	1/11	0/11
Total	**122**	**3.2%**	**4.0%***	**13.1%**	**9.8%**

* Mealybug were only found in central Qld.

Cotton Bunchy Top Virus

Samples to determine the presence of Cotton Bunchy Top Virus (CBTV) were selectively taken from perennially growing plants that exhibited symptoms of disease during the pre-season survey. These samples demonstrated that bunchy top was present in feral plants growing in the central Qld and St George regions.

Samples were not taken from the Emerald Irrigation area as Dr Murray Sharman had already collected samples from these areas and reported the results within his CBTD project. Instead, the more outlying areas on the Central Highlands were sampled (Fig 25). Samples collected from outlying areas on the central Highlands that were 5 km or more away from cotton production farms were negative for CBTD. The situation in the Dawson was similar, with positive samples only being collected from areas with cotton production nearby, except one site on the Dawson Highway between Moura and Banana (Fig 26).

A high incidence of CBTD was found within samples collected from the St George region. All of these samples were taken from locations within 5 km of cotton production fields. The positive site for CBTD on the Moonie Highway (Fig 27) corresponds with Photo 12.

Samples were not taken from feral plants on the Darling Downs or northern NSW as these plants had minimal green leaf material due to the impact of winter frosts.

Table 3. Details for samples collected and tested for CBTD using PCR.

Region	No Plants sampled	CBVD	% Infected
Pre-Season			
Central Qld	13	4/13	30%
St George	8	6/8	75%
Total	21	10/21	47%

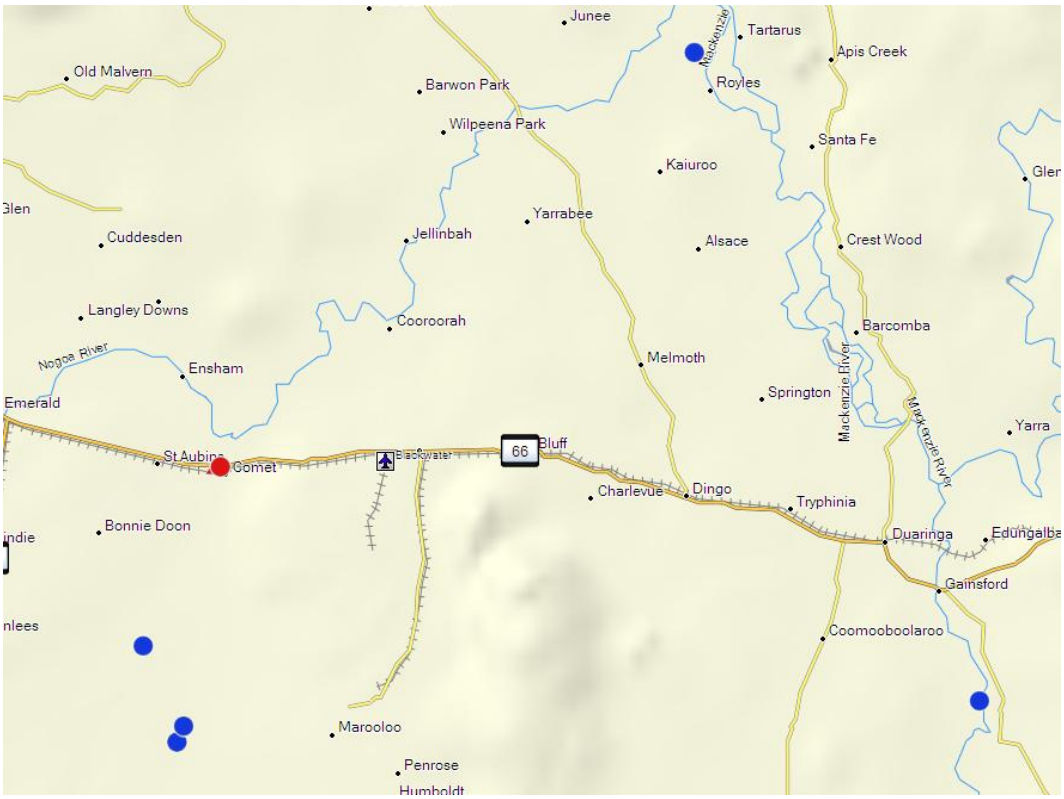


Figure 25. Pre-season samples taken for CBTD from the Central Highlands (outlying areas only). Blue markers indicate that no disease was detected, red markers are positive for CBTD.

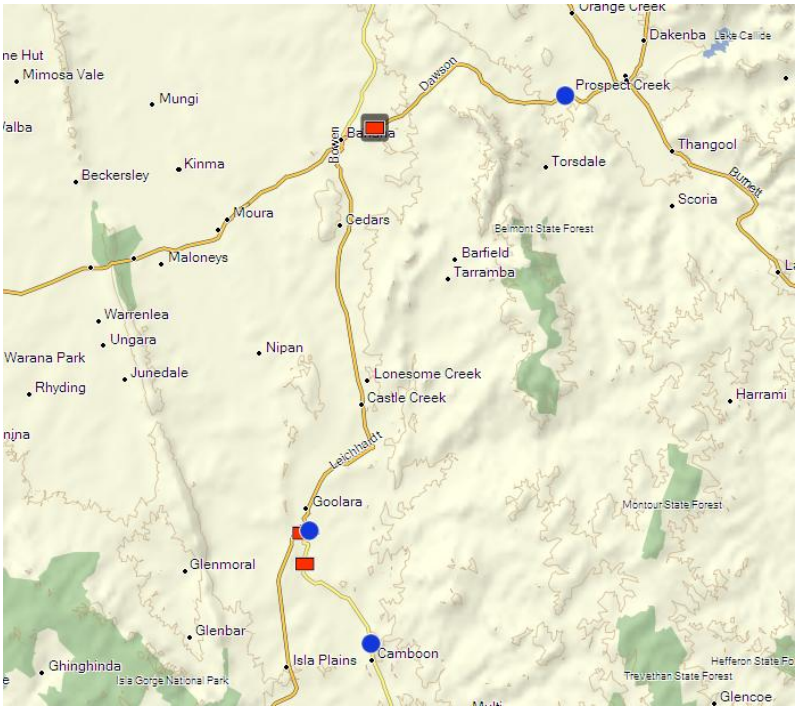


Figure 26. Pre-season samples taken for CBTD from the Central Highlands (outlying areas only) and Dawson Valley. Blue markers indicate that no disease was detected, red markers are positive for CBTD.

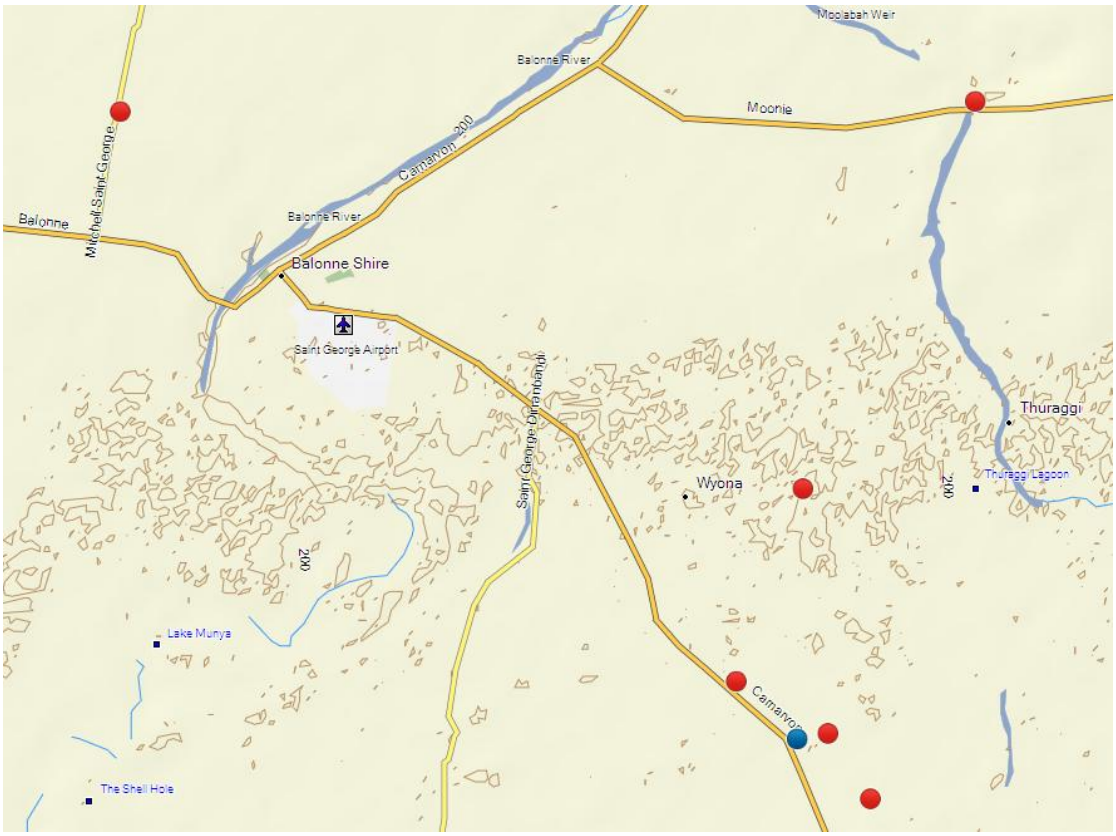


Figure 27. Pre-season samples taken for CBTV in the St George region. Blue markers indicate no disease detected, red markers are positive for CBTV.

Post-season feral plant survey

A post-season feral plant survey was conducted to determine changes in feral plant populations and CBTD levels in each of the regions. This survey revisited the areas where feral plants were present during the first survey, with particular attention given to the previously recorded GPS locations of feral plants to determine plant survival. Any new plants encountered were also recorded.

A point of interest during the second survey was the absence of young plants underneath previously recorded feral cotton plants. This concurs with observations by other researchers that the ability of these plants to recruit seedlings is very limited.

On the Central Highlands production region, 81 plants had disappeared, 45 remained, and 35 were new (or possibly unrecorded during the first survey). The majority of missing plants were from roadway areas that had been slashed or Sunwater drains that had been sprayed with herbicide (Fig 28).

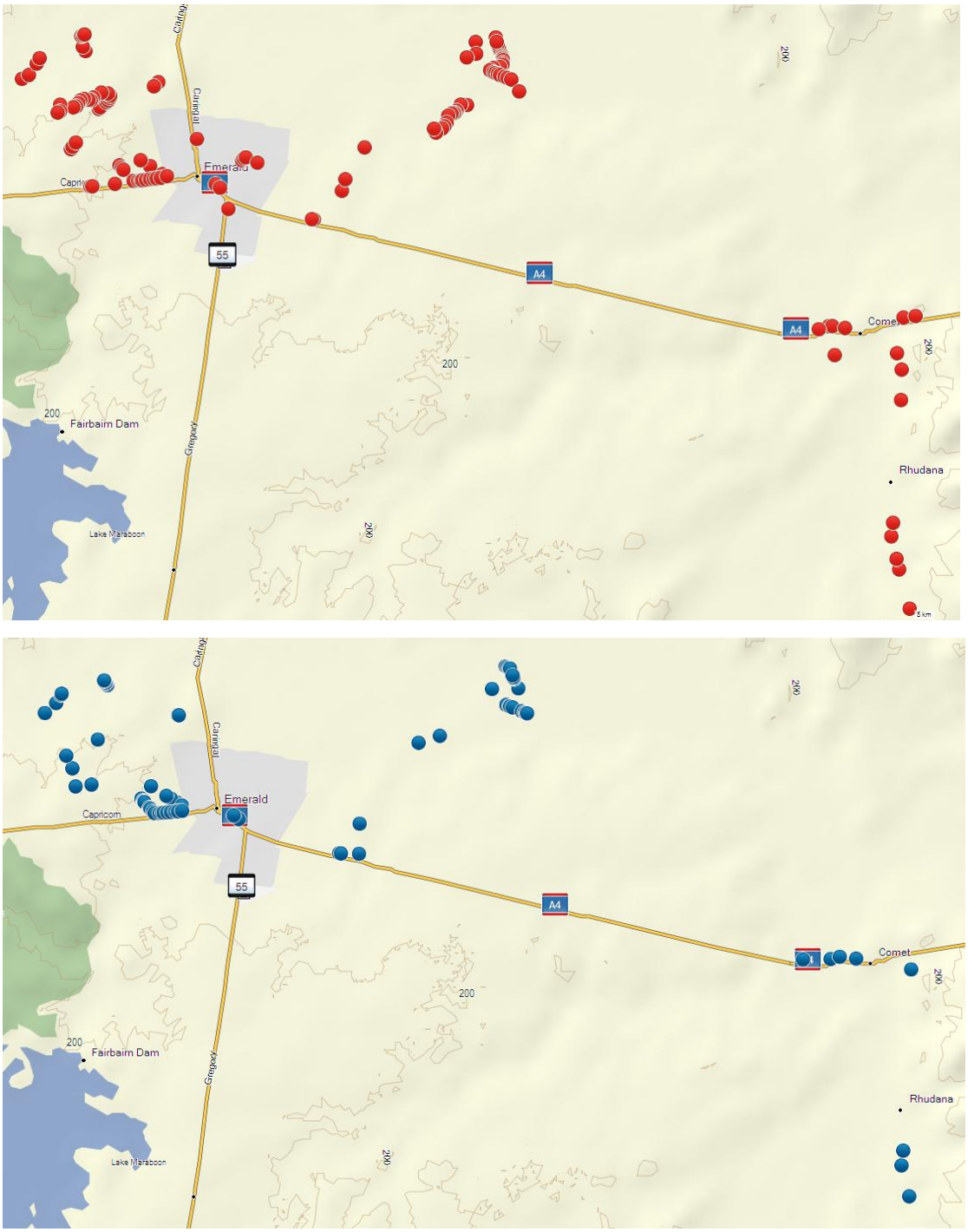


Figure 28. Central highlands region depicting pre (red dots) and post (blue dots) season feral plant survey points.

For the Dawson Valley production region, 46 plants were lost, 26 remained, and 15 were new (or potentially unrecorded during the first survey) (Fig 29). The majority of missing plants in the Dawson were lost from roadways that had been slashed, burned by fire or disturbed by civil construction.

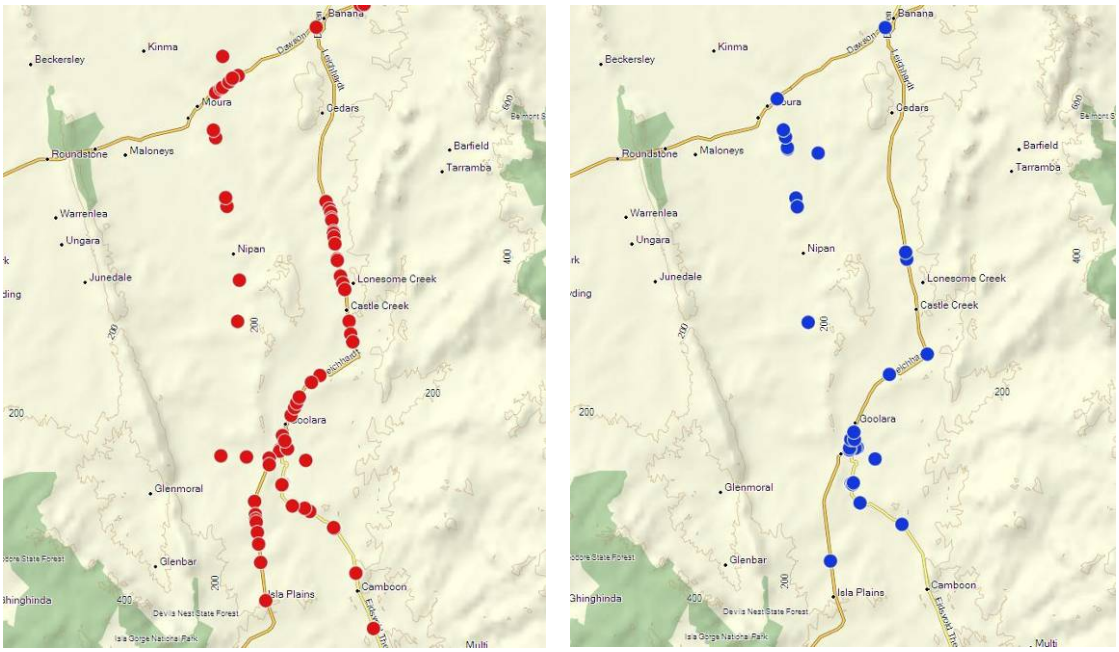
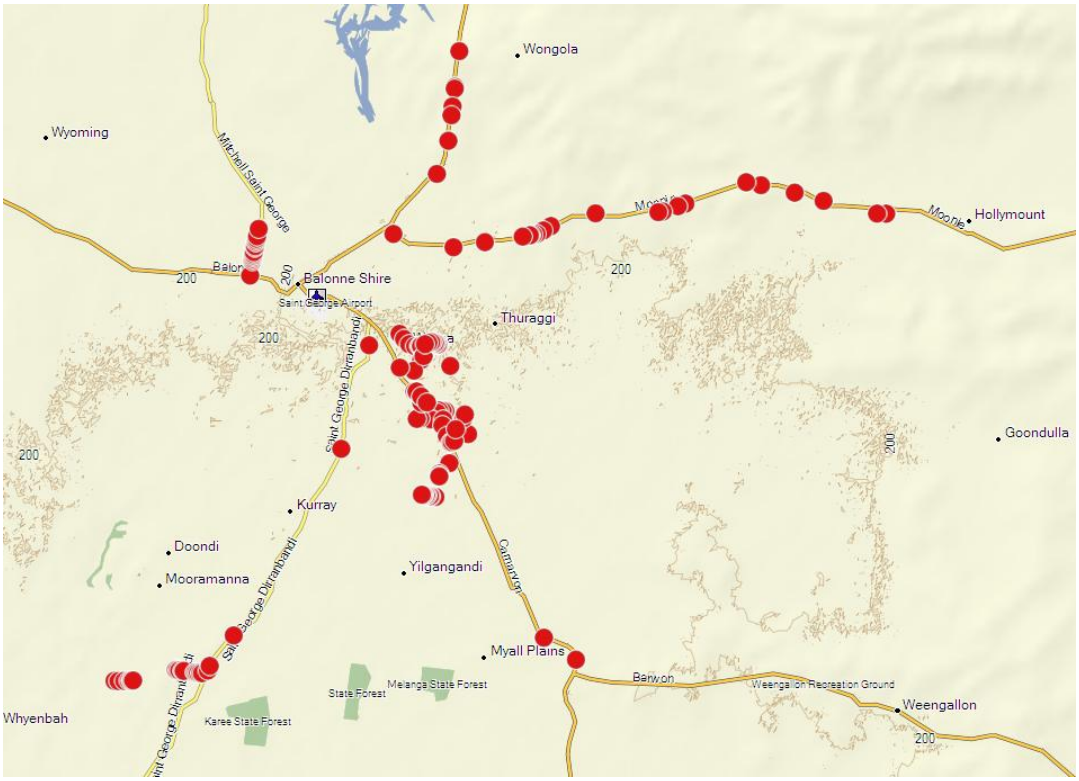


Figure 29. Upper Dawson Valley region depicting pre (red dots) and post (blue dots) season feral plant survey points.

For the St George production region, 61 plants were lost, 57 remained and 108 were new (or potentially unrecorded during the first survey) (Fig 30). Again in this region the majority of missing plants were lost from main highways that had been slashed or disturbed by road works. The majority of existing plants in the irrigation area remained between surveys and the majority of newly recruited feral plants were found within the irrigation area.



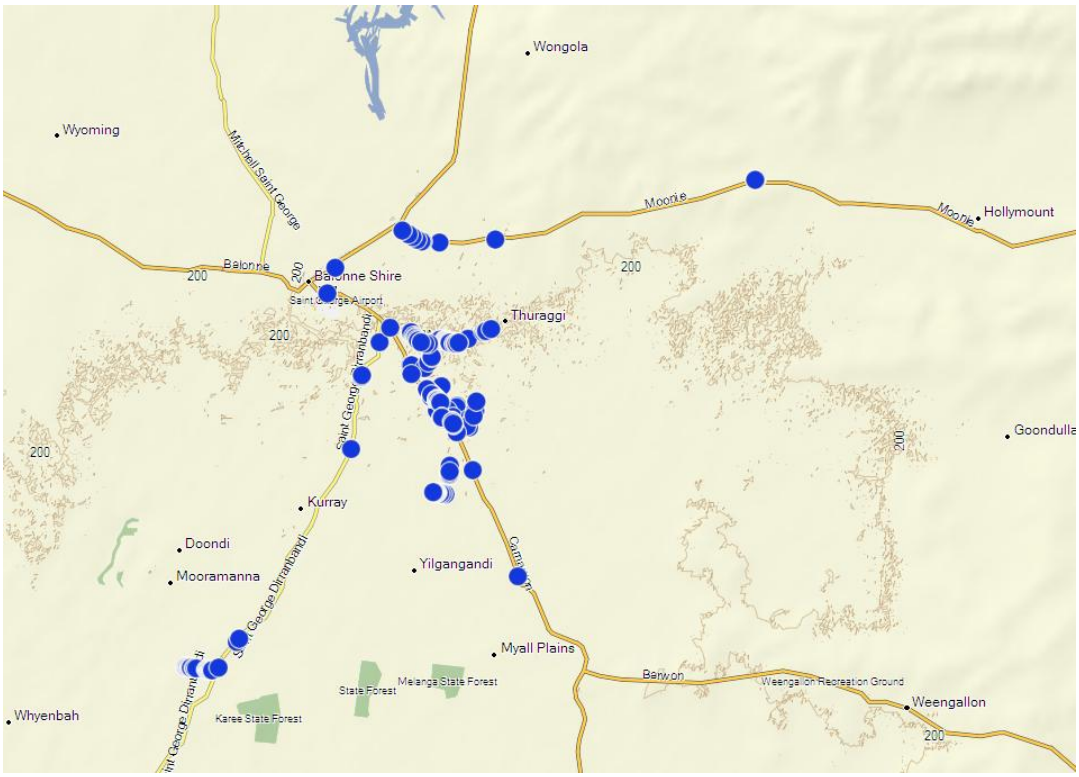


Figure 30. St George region depicting pre (red dots) and post (blue dots) season feral plant survey points.

In the cooler regions like the Darling Downs, key differences were found in terms of feral plant recruitment. A comparison with the pre-survey 39 plants were lost, 31 remained and 275 were new (or potentially unrecorded during the first survey) (Fig 31). This recruitment may be a function of good summer rainfall and the record 2011/12 crop that was picked and ginned late, which meant that cotton modules were still being transported in early spring. The record size of the 2011/12 crop potentially resulted in more seed cotton being spilt onto roadway areas. The extensive number of new plants on the Warrego highway was due to recently completed road works whereby disturbance to the roadsides had incorporated seed cotton which had subsequently grown. This section of roadway is a major thoroughfare for modules transported from the western downs to the Qld Cotton gin on the western side of Dalby.

A number of feral plants were recorded as growing perennially during the first survey even though they were badly frosted and it was unclear if these plants would continue to survive through the next summer season. The decision to record these plants as perennial at the time was based on the presence of live tissue (leaves or bark). Many of these plants went missing along roadways, however in protected locations these plants survived and regrew quite successfully if they were undisturbed. Photos 15 and 16 show examples of regrowth from cotton plants on the Darling Downs.

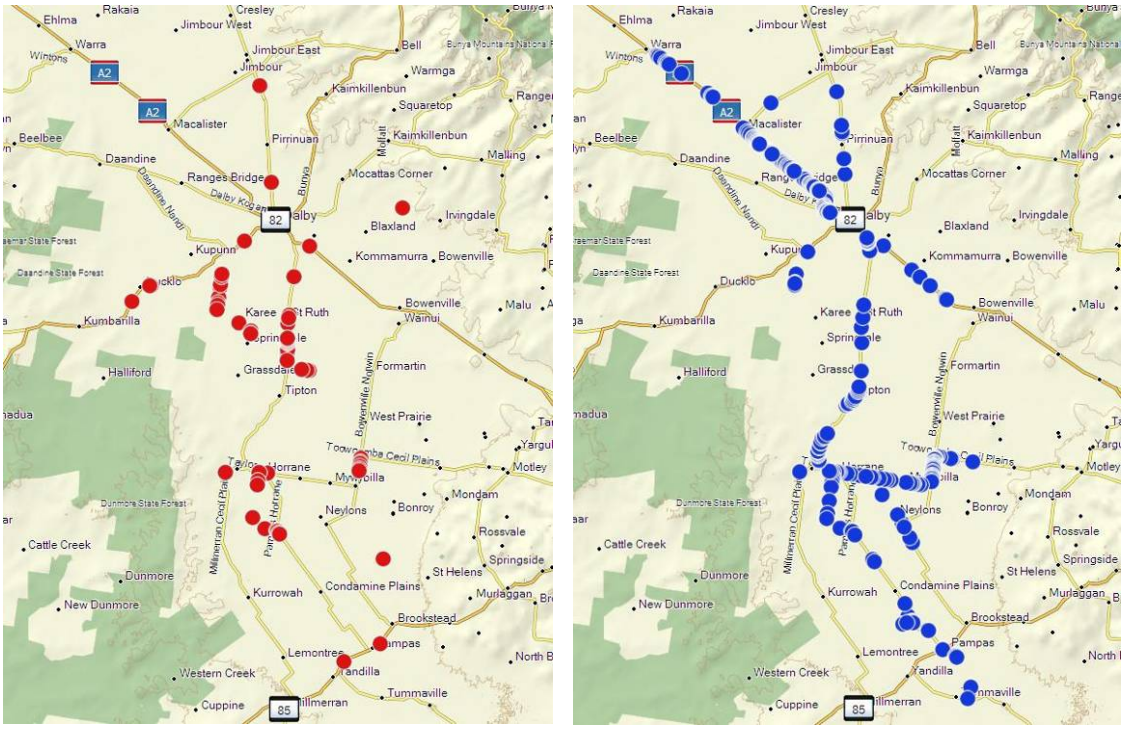


Figure 31. Darling Downs region depicting pre (red dots) and post (blue dots) season feral plant survey points.

Photo 15. A comparison between plants logged as perennial at the end of winter (left) and mid Autumn (right) on the Cecil Plains Dalby road. Despite being set back by cool winter temperatures, these plants were able to survive and regrow. Plants at this site tested positive for CBTD.

Photo 16. Another example of a cotton plant on the Darling Downs that was very badly affected by frost during winter (left photo taken in September). With only minor shoots of green material at the base, it was able to regrow during the summer as the autumn image shows (right).

Within northern NSW, only the Newell highway was surveyed twice. During this survey only 3 plants were logged on the pre-season trip which subsequently could not be found. However, 61 new seasonal plants (or plant patches) were subsequently logged with many of these plants being associated with roadside disturbance from recent road works (Fig 32).

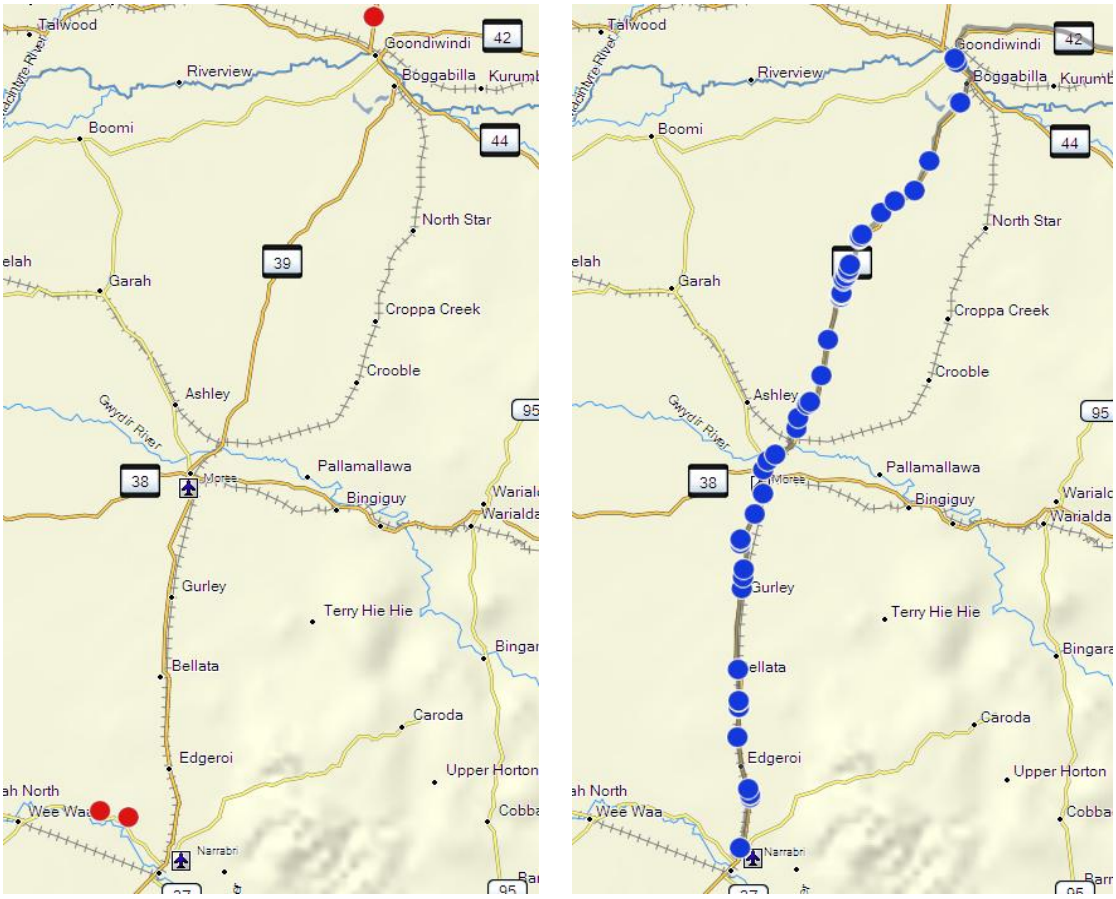


Figure 32. Survey of Newell highway from Goondiwindi to Narrabri and the road to ACRI depicting pre (red dots) and post (blue dots) season feral plant survey points.

Photo 17. Feral plants growing in a protected place on a Newell Highway creek crossing during April 2013. These plants were seasonal recruits with no evidence of old growth from a previous season.

Cotton Bunchy Top Disease (CBTD)

During the post-season survey, samples were again taken to determine the presence or absence of CBTD. For this survey, plants were sampled randomly (the pre-season survey only sampled plants showing disease symptoms). In this case, many of the plants sampled showed limited evidence for CBTD infection. Samples were collected from the Central Highlands, Dawson, Darling Downs and St George regions. The results from these samples show a relatively high incidence of CBTD, particularly from samples taken within the CQ and St George irrigation areas where cotton fields were nearby. Table 4 and Figures 33-36 depict the results and geographic location for the samples taken.

Table 4. Details for samples collected and tested for CBTD using PCR.

Region	No. plants sampled	CBVT	% Infected
Post Season			
Central Qld	22	14	63%
Darling Downs	24	7	29%
St George	13	7	53%
Total			

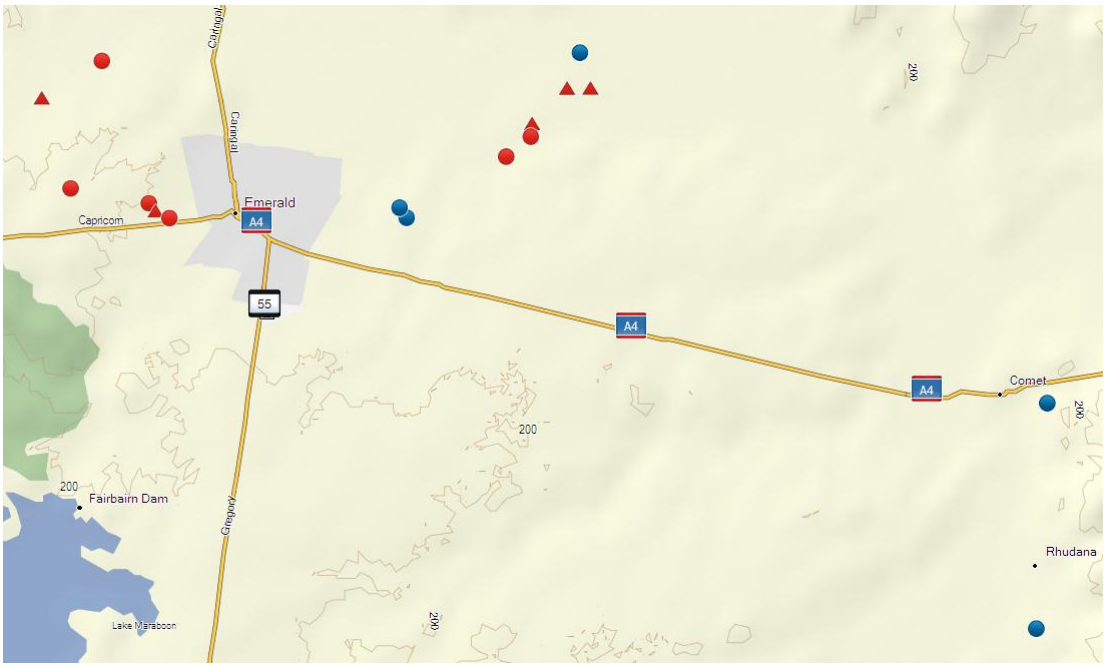


Figure 33. End of season testing results for CBTD in the Central Highlands. Blue markers indicate no disease detected, red markers are positive for CBTD. Note the close proximity of the positive CBTD samples to the irrigation areas.

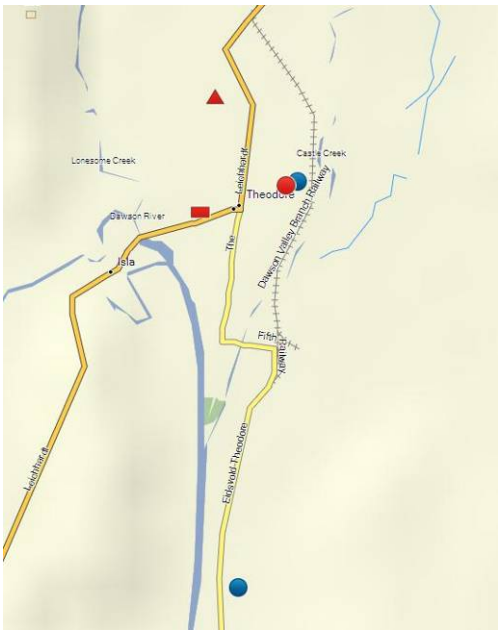


Figure 34. End of season testing results for CBTD in the Theodore irrigation area. Blue markers indicate no disease detected, red markers are positive for CBTD.

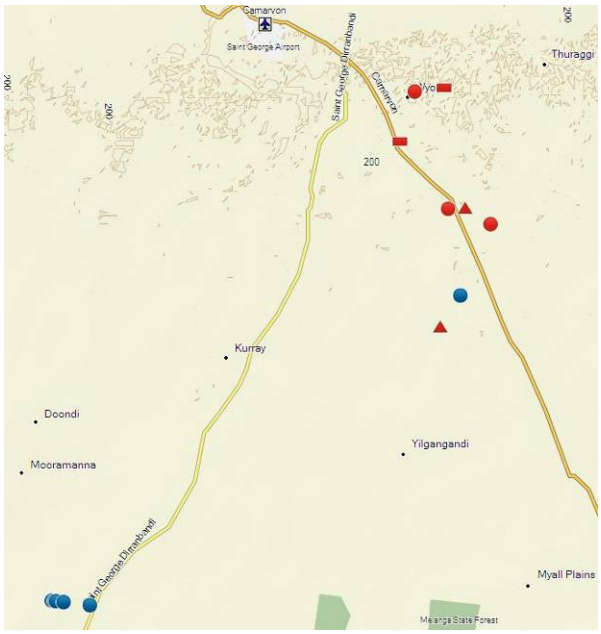


Figure 35. End of season testing results for CBTD in the St George irrigation area. Blue markers indicate no disease detected, red markers are positive for CBTD.

Note *the close proximity of the positive CBTD samples to the irrigation areas.*

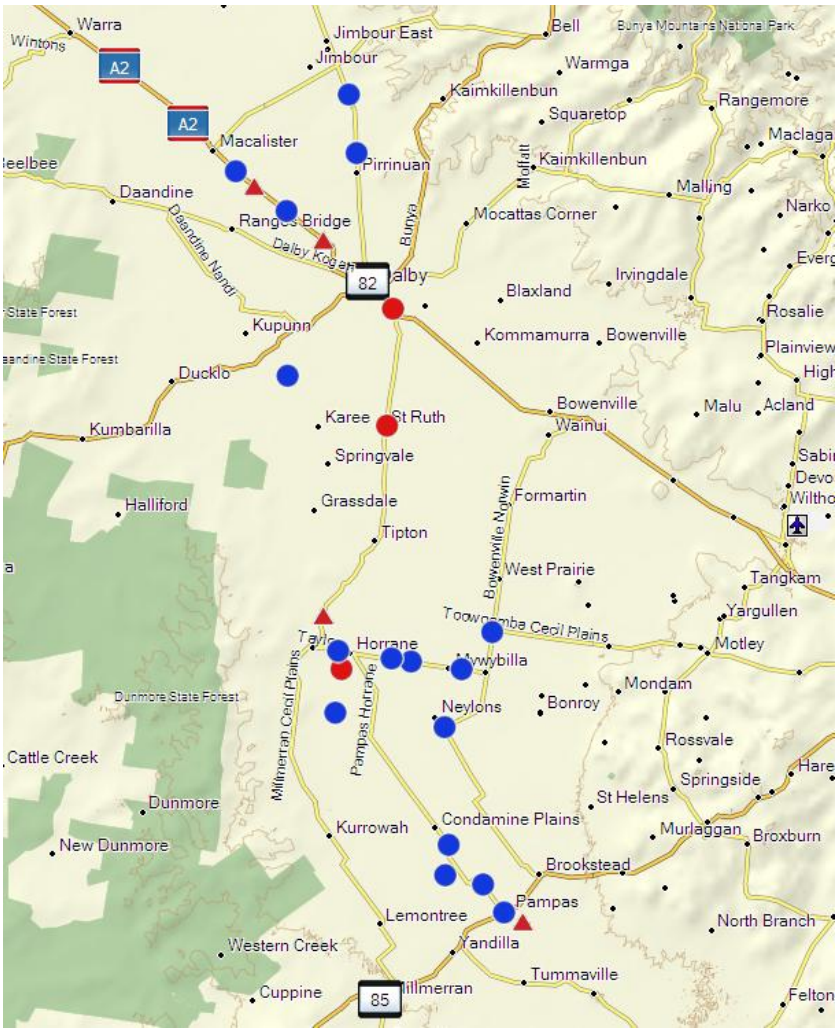


Figure 36. End of season testing results for CBTD in the Darling Downs region. Blue markers indicate no disease detected, red markers are positive for CBTD.

Survey of NQ cotton transport corridors

A survey was conducted of the main roadways that connect the Burdekin, Atherton and Richmond regions and ginning facilities on the Central Highlands. The survey of roadways between Atherton, the Burdekin and Emerald covered 2402 km during which only 12 locations with one or more plants were recorded. Of the 40 roadside locations Farrell and Roberts (2002) surveyed, 36 were revisited and examined for cotton plants. Only one of these sites (near Mt Garnett) contained feral cotton, which ironically was one of the few sites found to harbour plants in 2002. The other 11 locations where cotton was present were new sites. Two of these locations contained larges patches of plants resulting from transport accidents involving overturned loaded module trucks (Photos 18 and 19). The waypoints for these locations can be found in the Google Earth application that forms part of this report.

Samples collected from plants in NQ tested negative for CBTD. However, small numbers of *Solenopsis* mealybug were present on a plant located near Atherton as well as on all plant patches encountered between Charters Towers and Emerald.

Within the Burdekin irrigation area, no plants were found along the main roadside areas or along the Barratta creek drainage system. The four plants recorded occurred along farm boundaries where cotton had been grown previously at Clare and Millaroo; specific details are recorded within the Google Earth record of the survey.

The distance surveyed between Emerald, Richmond and Charters Towers totalled 1025 km. During this survey regular stops were made approximately every 50 km to search for plants as well as visual scanning of the roadsides during travel. No feral plants were located.

Photo 18. A large patch of perennial cotton plants growing between Capella and Clermont. The origin of these plants was due to a transport accident which spilt a module onto the roadside several years earlier. *Solenopsis* mealybugs were present on these plants. Sampling for CBTD was not done as earlier sampling by Murray Sharman (QDAFF) had already confirmed the presence of the disease at this site.

Photo 19. A large patch of perennial cotton plants growing between Belyando and Charters Towers. The origin of these plants was due to a transport accident which spilt a module onto the roadside in 2009. *Solenopsis* mealybugs were present on these plants. Samples collected were negative for CBTD.

Photo 20. A roadside plant south of Charters Towers. Civil construction has assisted germination and establishment. A sample collected was negative for CBTD.

Photo 21. A roadside plant growing on a verge near the town of Atherton. This plant had a *Solenopsis* mealybug present. A sample collected was negative for CBTD.

Photo 22. These two plants were found growing on a roadside verge near Mt Garnett in NQ. A sample collected was negative for CBTD.

Discussion

The purpose of this study was to determine the extent to which feral cotton plants with transgenic traits have established within and around Queensland's cotton production regions and transport networks and to ascertain the risk that these plants might pose from a plant protection, biosecurity and transgenic stewardship perspective. This report identified that significant populations of feral plants were mainly located in and around the local roadway networks and drainage systems of Queensland's cotton cropping areas and that this is likely to be a more persistent problem in the warmer areas of central and southwest Qld. In comparison, on the Darling Downs, winter frosts/cooler conditions reduce the number of feral cotton plants that can survive perennially. Perenniality of plants in these areas between season is dependent on the severity of cold winter temperatures and the immediate environment that may offer protection against frost eg road culverts and overhanging trees.

Pre-season feral plant surveys

In general terms the incidence of feral cotton plants was directly related to the proximity of nearby cropping or the transport of modules on local roadways. The incidence of feral cotton plants at distances of more than 5 km of cropping areas or ginning facilities was low.

These feral cotton plants originated either from seed cotton that had floated out of production fields on overland flow and into common drainage channels or from seed cotton spilt during the movement and transportation of cotton modules.

The incidence of roadside feral cotton plants is low compared to the quantity of seed cotton that is spilt and litters most roadways between production areas and ginning facilities. Clearly the majority of spilt seed cotton fails to germinate and establish new plants. Civil construction was found to be an important factor for increasing the rate of successful establishment for plants that occurred on roadways. Plants were typically found in protected microclimates associated with roadside structures such as culverts, signs and guide posts. The reason for the high incidence of plants in these places was unclear but might be due either to the creation of conditions that allow seed cotton to lodge and germinate between the concrete and surrounding soil and gravel. Alternatively it maybe that the survival of germinated seed cotton is greater in these locations due to differences in the retention of soil moisture compared with the surrounding environment and the protection provided from roadside mowing. These sites are also often sprayed with glyphosate herbicide that kills off competing weeds.

Road construction and disturbance was found to be a significant factor for increasing the incidence of feral cotton plants. In the process of construction or roadside grading, seed cotton can become incorporated, which greatly increases germination and subsequent establishment of plants. In these areas, large numbers of feral cotton plants can be seen growing in defined bands along several kilometres of roadside (Photo 23).

Photo 23. An example of roadside disturbance from grading which has resulted in the incorporation of seed cotton. As this is an isolated local roadway, roadside mowing whereby these plants could be competitively disadvantaged by grass re-growth is unlikely to occur.

The survival of roadside plants that established due to civil construction disturbance was found to reduce over the longer term on major highways such as the Warrego and Dawson. The regular programs of roadside maintenance such as mowing greatly reduce the capacity of these plants to survive and compete with surrounding grasses.

A follow up survey just prior to the submission of this report for the Warrego highway between Dalby and Macalister demonstrates the impact of roadside maintenance combined with winter temperatures on feral plant populations. This section of highway was found to harbour a very large number of recently recruited feral cotton plants during late summer. The establishment of these plants was due to spring road works that incorporated spilt seed cotton and aided germination (Fig 36). The follow up survey during the first week of September found that a large proportion of these plants had perished due to roadside slashing with only 32 plants located for this highway section compared to an original measure of 111 (Fig 37). What is also clear for this section of highway was that the only surviving plants were those that evaded slashing by either being located well off the roadside (Photo 24) or being protected by a roadside structure such as a culvert or sign post (Photo 25). Despite being frosted severely, these plants were still found to be surviving perennially with evidence of regrowth at the base of each plant (Photos 25).

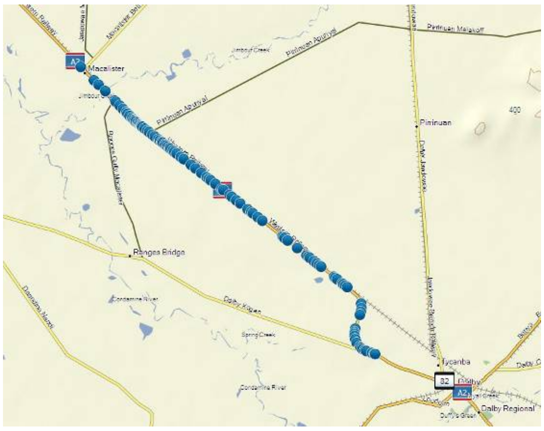


Figure 36. Survey of Warrego highway between Dalby and Macalister during April 2013.

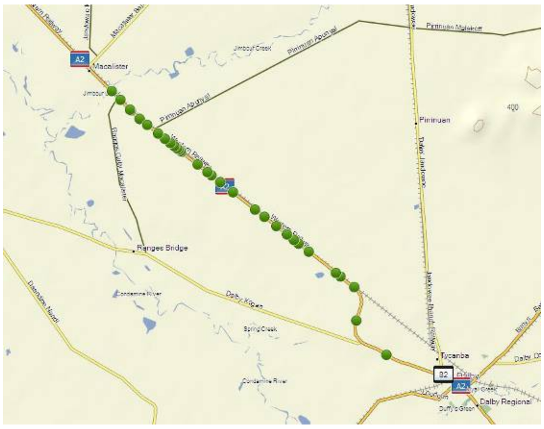


Figure 37. Survey of Warrego highway between Dalby and Macalister during early September 2013 after winter and roadside slashing.

Photo 24. Depicts an example of the plants left after winter and roadside slashing operations. No plants were found in the slashed area beside the road. All plants found were outside of the slashed section or beside obstructions such as sign posts. 79 plants were lost along this highway section between the two surveys due to slashing.

Photo 25. Despite appearing to be killed by frost, most feral plants along the Warrego highway after winter had signs of regrowth at the base.

The health and vigour of the majority of feral plants located during the pre-season survey was low. In the colder regions such as the Darling Downs and Northern NSW most plants had been frosted off, with the only signs of survival being limited budding activity at the base of the plants or green tissue under the bark when cut. Many of the plants found in CQ and St George were also in poor health with major dieback of the outer branches, but retained scrappy, green canopy foliage.

Pest insect abundance on feral plants pre-season was relatively low with very few plants found to be hosting important pests such as cotton aphid (*Aphis gossypii*) and mealybug (*Phenacoccus solenopsis*). This was surprising and suggests that pest populations on feral plants within the broader landscape are unlikely to be significant drivers of new season pest outbreaks. Pest presence may be highly variable on feral cotton plants depending on weather conditions. The cold temperatures and regular frosts of the 2012 winter left many plants alive but in very poor condition which may be a causal factor for the low abundance of pest insects observed. A proportion of plants exhibited signs of historical insect activity such as parasitism mummies or exuviae (skins) from earlier aphid populations being found. This combined with the relatively high incidence of CBTD amongst feral plants within the irrigation areas of CQ and St George suggests that aphid populations moving within the broader environment will use feral cotton plants as intermittent hosts. Once infected, perennial cotton plants will serve as a disease reservoir that may infect subsequent aphid populations that pass through. Interestingly CBTD was generally only found on feral cotton plants within 5 km of cotton producing areas with samples taken from more isolated places in NQ, CQ and south west Qld testing negative.

One hundred percent of the samples collected from feral cotton plants during the pre-season survey tested positive for either Bt, Roundup or typically both traits. For all samples that tested positive for Bt both Cry1ac and Cry2ab were present. This was not unexpected given the near 100% penetration of transgenic traits within the Australian cotton market place since 2006.

Post season survey comparisons

The second survey of each of the cotton regions demonstrated that feral plant populations are subject to significant levels of recruitment and turnover. This was particularly evident for feral plants growing on major highways where many of the plants identified during the first survey were not found during the second survey. Many of these plants had been destroyed by mowing, fire, or roadside disturbance due to road works, or had died out due to changing environmental conditions.

This contrasted with feral plants located on local roadways within the irrigation areas of CQ and St George. In these areas feral plants were generally found to have survived during the summer season. The causal factors for this may be that these plants were generally growing in better quality soils that occur within the irrigation areas compared to outlying connecting transport corridors which are typically adjacent to grazing country with shallower soil types. Another key difference could be the regularity of roadside mowing that for highways is funded by State Government authorities whereas local roads are managed by local councils.

The post season survey identified large numbers of newly recruited cotton plants in all of the areas surveyed, but particularly on the Darling Downs and along the Newell highway in NSW. It was unclear whether this is an annual event with most plants subsequently not surviving winter. Alternatively, the high numbers of plants may correspond with the previous season being a large production year and consequently a greater amount of seed cotton spilt onto regional roadways. This combined with good summer rainfall may have contributed to greater feral plant establishment.

Randomly collected samples for CBTD taken from perennially growing feral cotton plants again showed a high level of disease incidence within the irrigation areas compared to outlying sites.

Aphid activity on these plants was minimal, but evidence for earlier aphid presence could be found on some plants and the high presence of CBTD demonstrates that aphid populations regularly utilise these plants as a host.

Of all of the irrigation regions surveyed, feral plants growing along roadsides were found to be the most abundant in the St George irrigation area local road network. Many of these plants could be easily controlled with roadside slashing but it was evident between the two surveys that these areas are not subject to a regular mowing program. The majority of feral plants in this area would be eliminated with such a program. These plants also had a high incidence of CBTD and were nearly always in close proximity to cotton fields.

North Qld survey

Very few cotton plants were found on the NQ survey trip, which was similar to the findings of Farrell and Roberts in 2002. Using the previous methodology for the original survey only one site near Mt Garnett was found to have feral cotton. Ironically this site was one of the 3 (out of 40) stops where cotton had been found in 2002. The plants found growing at this particular site were very similar the plant photographed and described in 2002 — stunted with little obvious chance for recruitment. Given the distance of this site from cotton production areas and the presence of two plants at this location, a probable causal factor is that fuzzy cotton seed used for animal feed was carted through this area on a regular basis. Indeed there was a stockfeed supplier located several kilometres south of this location.

There was no evidence for the presence of cotton at either of the other two sites where cotton had been previously recorded. There was also no evidence for seedling recruitment at any of the other sites were cotton was found with all plants being of a similar age and no evidence of seedlings growing below or around established perennially growing plants.

An interesting aspect of the NQ survey was that since the original 2002 survey there has been limited commercial cropping of cotton in the Burdekin region since 2007. During this period approximately 18,000 bales worth of seed cotton was transported from the Burdekin by road via Charters Towers to Emerald. This transport route overlapped a significant portion of the previously surveyed roadway. Despite the regular cartage of cotton modules over a 6 year period, there was no evidence to suggest that the incidence of roadside feral cotton had increased. Of the 3 locations where cotton was found between Ayr and Clermont two sites had singular plants and the third was a site where a load of round modules from the Burdekin overturned in a traffic accident during 2009. The spilt seed cotton was subsequently burnt but enough remained to give rise to a thick but relatively contained patch of feral cotton. All of the modules carted from the Burdekin to Emerald were covered during transport. The lack of feral plants along this transport corridor is likely due to the efforts made by Burdekin growers to cover modules prior to transportation.

The other interesting aspect for the feral plants found growing along the NQ roadways was that plants at each of the logged sites had *Solenopsis* mealybug except the two very small plants recorded near Mt Garnett.

Differences between hot and cooler regions

Generally, the central Queensland and St George production regions harboured significantly greater numbers of perennially growing feral cotton plants at the start of the growing season compared to the Darling Downs and NSW regions. The key difference between these areas in terms of feral plant survival success would appear to be the extent of cold temperatures and frost during winter.

The feral plants growing in the warmer areas were generally in better condition in terms of having green foliage at the beginning of spring compared to most plants observed on the Darling Downs and northern NSW regions which had been badly affected by frost.

These same southern areas have significant potential to recruit new feral plants as observed during the post season survey in autumn. However, the survival of these plants during winter is limited to those that typically germinate in a space that enables greater frost protection during winter.

What industry biosecurity threats are posed by feral cotton?

This survey has provided a comprehensive snapshot in time of the presence and location of feral cotton growing throughout Queensland and parts of northern NSW's cotton growing regions and transport corridors. It could be argued that the quantity of feral plants recorded during this survey, particularly for roadsides, is likely to represent a population peak when the preceding wetter than average seasons, record cotton crop acreages (and associated record module movements), and extensive road works due to flood repairs in Queensland which might serve to incorporate seed and enable recruitment are taken into account.

The potential risks posed by feral plants ultimately depend on the types of plant protection scenarios considered.

The potential interaction between pest insects of concern, feral cotton and the Australian cotton industry is likely to be influenced by the ability of feral plants to provide:

1. a meaningful resource for on farm pest species to allow transitioning and/or survival of pests, resistant alleles, and vectored diseases between space and time.
2. additional exposure of Lepidopteran pests to Bt toxins that occurs outside of the confines of an RMP and associated TUA.
3. an off-farm resource for exotic pests such as boll weevils should this pest ever occur in Australia.

The first scenario is likely to be of most concern for the cotton industry with the presence of feral cotton plants in the broader farmscape being contrary to the significant emphasis and effort made by industry to maintain high levels of on farm hygiene. The actual ability of feral plants to provide pests with a host to survive between seasons or move between regions is likely to depend on the geographic location of plants in relation to nearby cropping and whether or not plants can grow perennially in sufficient health throughout the year to attract and support pest activity.

Perennially growing plants along drainways and local roadways within the irrigation areas are likely to have the greatest potential for providing a green bridge for plant pests and diseases between seasons. Plants growing in interface areas adjacent to farming fields would also be of significance. This is also more likely to be of greater importance in the warmer areas of CQ and St George where feral plants generally had more green foliage available to host insects such as aphids compared to the Darling Downs and northern NSW where frost damage had made surviving plants unattractive. The actual evidence for feral plants harbouring significant populations of pest insects such as aphid and mealybugs during the pre-season was low for the 2012/13 season. Less than 5% of plants were found to harbour these pests during the early spring surveys. However, the preceding winter season was very cold which may have limited pest activity, whilst the high incidence of CBTD in perennially growing feral plants and evidence of historical aphid activity suggests that these plants are probably intermittently infested by aphid populations.

The pest and disease vectoring potential of these transitional populations is unclear as there was no way of comparing pest presence on feral plants with that of the populations of mealybug and aphids in the broader agricultural landscape. However, it would be prudent to exercise control where possible on feral plants that occur within near proximity to cropping fields as these are a potential source of pests that may vector disease into newly sown crops and/or carry pesticide resistance alleles.

Photo 24. This long term feral cotton plant was found growing on a roadside at the interface of a cotton farm near Theodore. This plant was found to be positive for CBTD and is only 20m from commercial cotton cropping. There are too many examples like this found during this survey.

Feral plants that occurred at distances greater than 5 km from cropping areas were relatively infrequent and it is our view that these plants pose minimal threat for transitioning pests and the diseases that they might vector through space and time. This is supported by there being very few positive tests for CBTD taken from isolated feral plants.

With regard to the slowly rising frequency of *Helicoverpa* spp. that carry resistance alleles to Bt proteins (namely Cry2ab), it is difficult to associate any trend with the presence of feral plants within agricultural landscapes. Feral plants were found to constitute a miniscule component of the vegetation that occurs on drainage lines and roadways, and these plants are most attractive in summer after rainfall when there is a large amount of competing vegetation available for ovipositing moths.

The potential for feral plants to complicate the management of a new exotic pest such as boll weevil would be significant, particularly in the warmer production regions. Nearly all of the feral plants logged had significant numbers of bolls that would serve as an important resource for pests such as boll weevils. Whilst this is not an immediate management issue, it would factor strongly in any future management plan should boll weevil be detected in Australia.

The primary disease threat that feral cotton plants present is for harbouring vectored diseases such as cotton bunchy top disease. A high proportion of plants tested positive for CBTD from within the irrigation areas. The disease implications for these infected plants in relation to commercial cropping is unclear as there is no comparison between the disease status of feral plants with that of other host weed species (e.g. marshmallow) and the relative attractiveness of these alternate hosts which can be common in the irrigation areas. However, there were many instances where feral plants that tested positive for CBTD occurred within line of sight of commercial cotton crops, suggesting the potential for disease to be vectored into new season crops is potentially high. Again it would be prudent for growers to control (where practical) feral cotton plants growing in areas adjacent to cropping fields. St George in particular had a very

high incidence of perennially growing cotton plants throughout the drains and roadways of the main irrigation area. All of the plants sampled from this irrigation area tested positive for CBTD and the majority of these plants could be easily targeted by roadside mowing and a basic herbicide program for the drainage channels.

In the current context of plant protection issues facing the industry, the extent to which feral cotton plants occur and their potential impact for pest and disease management is somewhat minor. The biggest issue is simply the close proximity of most plants to nearby cotton production areas and the high levels of CBTD infection. From a biosecurity perspective these plants would be much more problematic should the industry ever experience the incursion of a new disease such as Cotton Leaf Curl Disease or boll weevils.

Feral plants and stewardship of transgenic technologies

All of the samples taken during the pre-season survey tested positive for either Bt or RR technology and in most instances both traits. As these plants were found to occur on public or private property that belongs to non-cotton producers they fall outside of the confines of individual technology user agreements and relevant stewardship programs. The occurrence of transgenic feral plants in and around cotton production regions is an unintended consequence of transgenic cotton production. These transgenic plants in the broader environment may present challenges for the industry, technology owners, and the broader community.

Transgenic feral cotton plants present a challenge for the Australian cotton industry and technology owners (Monsanto and Bayer). Aside from the bio-security and plant protection reasons already outlined, the presence of these plants outside of farmers' fields could be exploited negatively by opponents to genetically modified technologies. These plants could be used to support arguments for unintended consequences associated with genetically modified organisms that in this case have escaped a farmers field and transitioned into the broader environment. The argument could be made that this represents contamination of non-crop areas and a failure by industry to implement effective technology stewardship.

For the broader community, transgenic feral cotton plants with herbicide tolerant traits present additional difficulties for local authorities tasked with roadside maintenance. This has been a point of conflict between cotton growers and local government authorities in central Queensland whereby herbicide spraying programs with glyphosate for the control of roadside weeds have become ineffective due to RR feral cotton plants. In response to this issue local growers put greater effort into covering modules during transport to reduce the amount of seed cotton spilt. Local government authorities might also consider utilising additional herbicides for roadside weed control. Essentially the advent of herbicide tolerant cotton varieties necessitates additional effort and resources from growers and the community to remedy this unintended technology consequence.

There was no evidence observed during the survey that feral plants give rise to new seedlings from the bolls that are produced. Whilst it is possible for the seed cotton produced on feral plants to fall to the ground and germinate, there were no instances of large established feral plants being surrounded by younger plants that would suggest successful ongoing recruitment. Where patches of plants were observed, these plants were generally of a similar composition in terms of plant size and structure. The survey did not find evidence for transgenic feral cotton plants to become invasive weeds in the sense that they give rise to self-perpetuating populations.

Therefore from a stewardship perspective, the abundance of feral cotton plants could be limited and better managed through the use of tactics that prevent the movement of seed cotton onto roadways.

Management for feral cotton plants

The incidence, location and patterns of recruitment for feral cotton plants generally has a number of positive implications for management within agricultural landscape. We draw the following recommendations and conclusions:

1. Many feral cotton plants were found in areas directly adjacent to cotton farms either along drainage lines or farm boundaries. In many cases these plants could be easily controlled by local growers whilst conducting typical on-farm hygiene operations. Therefore we would recommend that growers be encouraged to consider adjacent farm areas (boundaries and drainage lines) and where possible extend control actions to plants growing in these areas. These could be part of the farm hygiene extension messages that are communicated each season. The high incidence of disease found in feral plants within local irrigation areas would be a strong selling point for the value of such an approach. Farm hygiene extends beyond the front (and back) gate.

2. Cotton located along local roadways presents a particular challenge for the industry. Being on public space the industry cannot advocate that growers take direct control action due to public liability issues and the motoring public. For these plants it is recommended that the industry consider negotiating with local government authorities to implement control actions such as appropriate spraying and roadside slashing to lower the incidence of these plants.

3. Additional consideration should be given to adequate coverage of cotton modules during transport to minimise the loss of seed cotton along roadsides. This message has been already well adopted by industry but should continue to be a part of farm hygiene extension campaigns. Emphasis needs to be placed on ensuring that trucks leaving gin yards are also free of loose seed cotton. Many trucks leave gin yards with loose seed cotton still on trailer decks which subsequently litters surrounding roadways and is reflected by the high incidence of roadside plants within 5 km of ginning facilities.

4. St George CGA need to give serious consideration to tackling the widespread presence of feral plants along the local roadways and drainage lines in the channel irrigation area. All of the feral cotton plants sampled in the irrigation area tested positive for CBTD. This region could face significant crop protection issues should conditions be conducive to widespread early season aphid activity or if a new pest such as *Solenopsis* mealybug entered the region as is likely to occur at some point within in the next 3-5 years. The time to begin remedying this situation is now.

5. Subsequent recruitment from existing feral cotton plants is virtually non-existent and therefore feral cotton plant populations are not self sustaining. If the loss of seed cotton from on farm primarily during transport can be minimised, it would follow that feral plant population densities should decline over time.

6. Local CGAs in Emerald and St George should either enter into or continue discussions with channel infrastructure operators to enable the control of broad leaf weeds including feral cotton along common/shared drainage ways. Cotton is a poor competitor with stoloniferous grasses. A useful strategy may be to encourage these grasses on the inside walls of drainage lines to further disadvantage the establishment of cotton plants. Doing this by way of consultation may encourage better outcomes whilst also potentially avoiding contamination of nearby cotton crops with herbicides. These areas present a particular challenge for channel managers as all herbicides used need to be accredited as being "frog friendly".

7. Local government authorities consider using broad-leaf herbicide compounds with roadside preparations when spot spraying culverts and signage post areas within the St George and CQ cotton growing regions. Consultation between the industry and local government authorities

would be recommended to ensure that the timing of such applications is compatible with local cropping activities so as to reduce the possibility of drift.

8. The perennial survival of feral plants in southern regions is very much affected by frost and less complicated by shared field drainage infrastructure. The focus in these regions should be on controlling feral plants directly adjacent to production fields as well as minimising the loss of seed cotton from modules during transport.

Extension opportunities

The management of feral cotton plants is something that all growers can play an active part. From a practical perspective growers can implement practices that reduce the amount of cotton that is lost from modules during transport as well as enact active control on feral plants that were commonly found along farm boundary areas such as fence lines. The high incidence of CBTD found in these plants should provide an incentive for growers to take greater interest in control actions.

In terms of extension, feral plants control should be considered an important element of any campaigns conducted by the Cotton Info team that deal with farm hygiene and relevant pest and disease issues. Emphasis should be given on making growers aware of the mechanisms where by seed is lost during transport giving rise to feral plants as well as the importance for checking farm boundaries and onsite drainage lines for feral plants.

Extension for roadside plants and plant that occur along public drainage infrastructure will require a different approach. These areas cannot be managed by individual growers and extension efforts maybe better targeted at bringing together the various stakeholders (Sunwater, Local Govt, Main Roads, CGAs, Cotton Australia etc) to discuss the issue of feral plants and develop appropriate management strategies. This would be particularly useful for the St George and Central Queensland regions.

A Google-based map containing the GPS co-ordinates for all feral plants located during the survey tother with photographs is available on request from the project team at paul.grundy@daff.qld.gov.au

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References

Farrell, T & Roberts G. 2002. *Survey of Volunteers north of latitude 22° south.* Final report for Australian Cotton CRC, Narrabri NSW.

APPENDIX 1

GPS Coordinates of Roadside Survey Sites for North

Site Number	Start				Finish				Feral cotton 2002	Feral Cotton 2013
	Latitude		Longitude		Latitude		Longitude			
1	S	23°18.559"	E	148°06.620"	S	23°18.547"	E	148°06.513"	No	No
2	S	22°58.615"	E	147°50.087"	S	22°58.467"	E	147°49.851"	No	No
3	S	22°40.878"	E	147°43.729"	S	22°40.681"	E	147°34.559"	No	No
4	S	22°32.990"	E	147°30.842"	S	22°32.872"	E	147°30.888"	No	No
5	S	22°19.600"	E	147°17.455"	S	22°19.363"	E	147°17.323"	No	No
6	S	21°56.399"	E	147°03.234"	S	21°56.195"	E	147°03.096"	No	No
7	S	21°35.566"	E	146°54.208"	S	21°35.654"	E	146°54.209"	Yes	No
8	S	21°33.021	E	146°53.210"	S	21°32.901"	E	146°52.958"	No	No
9	S	21°20.119"	E	146°31.698"	S	21°20.372"	E	146°31.780"	No	No
10	S	21°09.662"	E	146°26.998"	S	21°09.852"	E	146°27.162"	No	No
11	S	20°56.114"	E	146°24.486"	S	20°56.378"	E	146°24.513"	No	No
12	S	20°49.313"	E	146°21.576"	S	20°49.367"	E	146°21.749"	No	No
13	S	20°33.949"	E	146°16.067"	S	20°34.179"	E	146°16.152"	No	No
14	S	20°09.513"	E	146°13.292"	S	20°09.776"	E	146°13.248"	No	No
15	S	19°49.059"	E	146°02.491"	S	19°49.105"	E	146°02.226"	No	No
16	S	19°36.742"	E	145°46.093"	S	19°36.583"	E	145°46.067"	Yes	No
17	S	19°32.497"	E	145°44.979"	S	19°32.279"	E	145°44.829"	No	No
18	S	19°14.953"	E	145°28.718"	S	19°15.099"	E	145°28.785"	No	No
19	S	19°11.049"	E	145°23.351"	S	19°10.935"	E	145°23.090"	No	No
20	S	19°00.265"	E	145°57.487"	S	19°00.155"	E	144°57.235"	No	No
21	S	18°55.566"	E	144°36.148"	S	18°55.423"	E	144°35.902"	No	No
22	S	18°34.481"	E	144°44.466"	S	18°34.269"	E	144°44.418"	No	No
23	S	18°10.007"	E	144°48.479"	S	18°09.750"	E	144°48.508"	No	No
24	S	17°47.179"	E	144°57.967"	S	17°47.016"	E	144°58.172"	No	No
25	S	17°38.988"	E	145°20.358"	S	17°38,868"	E	145°20.608"	Yes	Yes
26	S	17°30.056"	E	145°30.749"	S	17°31.866"	E	145°30.585"	No	No
27	S		E		S	17°20.423"	E	145°29.965"	No	No
28	S	17°18.077"	E	145°29.550"	S	17°18.821"	E	145°29,570"	No	No
29	S	17°26.336"	E	145°36.006"	S	17°26.611"	E	145°35.932"	No	No
30	S	17°34.571"	E	145°41.341"	S	17°34.764"	E	145°41.521"	No	No
31	S	17°34.142"	E	145°55.224"	S	17°34.048"	E	145°55.501"	No	No
32	S	17°31.045"	E	145°59.606"	S		E		No	No
33	S	17°43.844"	E	146°02.132"	S	17°43.655"	E	146°02.219"	No	No
34	S	18°11.995"	E	145°57.002"	S	18°11.752"	E	145°56.786"	No	No
35	S	18°34.093"	E	146°11.251"	S	18°33.728"	E	146°11.044"	No	No
36	S	18°49.477"	E	146°08.591"	S	18°49.246"	E	146°08.453"	No	No
37	S	19°13.441"	E	146°36.739"	S	19°13.325"	E	146°36.513"	No	Not Checked
38	S	19°36.536"	E	146°50.128"	S	19°36.798"	E	146°50.129"	No	Not Checked
39	S	19°50.254"	E	146°43.598"	S	19°50.241"	E	146°43.417"	No	Not Checked
40	S	19°54.490"	E	146°34.728"	S	19°54.617"	E	146°34.484"	No	Not Checked