Queensland Government

Asian honey bee Transition to Management Program

Spread of *Apis cerana* in Australia, 2007 – 2012

Department of **Agriculture, Fisheries and Forestry**

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Summary

Predicting the future spread of an invading species is important in order to predict potential impacts and to make timely management decisions in anticipation of the species' arrival in an area. This report presents results for the first of these approaches, exploring historical data in order to describe the spread of the Asian honey bee (AHB; *Apis cerana*) in Australia and to estimate spread rates.

This report aimed to fulfil QG2C & QG2D of the Asian honey bee (AHB) Transition to Management (T2M) Plan, i.e. to "undertake a spatial analysis of the current AHB infestation to guide future surveillance activities", and contribute towards AG3C of the AHB T2M Plan, i.e. to "model the population dynamics and drivers of spread".

Specifically, the report aimed to conduct a descriptive spatial analysis based on historical data (2007 to 2012), in order to:

- Describe the spread of AHB between 2007 and 2012 in terms of nest and swarm numbers, distance from original point of incursion, and increase in the known infested area over time.
- Explore the rate of spread and swarming capabilities.
- Determine any relationships between the number of detections, distance and area with staff numbers, public reports and meteorological variables.
- Describe seasonal variation in detections and its potential causes.

The results show that between 2007 and 2012, AHB detections have steadily increased at a rate of 22 new detections per month. The known infested area of AHB covers 490 685 hectares (as of October 2012). Spread rates were calculated at 1.86 km/month based on the maximum distance that swarms/nests were found from the Cairns Port (original detection), and 1.42 km/month based on the increase in the known infested area over time.

However, the actual spread of AHB does not appear to follow a steady rate. Increases in both the distance from Cairns Port and the overall known infested area have slowed substantially since 2010. This may be due to several factors: (1) the spread has indeed slowed, or (2) it has come across climatic or other boundaries (e.g. the western edge may be becoming too dry), or (3) it is an artefact of reduced surveillance along the increasing (and less populated) edge of the known infested area.

Introduction

Predicting the future spread of an invading species is important in order to predict impacts and to make timely management decisions in anticipation of the species' arrival in an area (Gilbert & Liebhold, 2010; Liebhold & Tobin, 2008). There are two conceptual approaches to predicting future spread: (1) analysis of and extrapolation from past patterns of spread, and (2) computer simulations using data on life-history traits within a mechanistic model (Liebhold & Tobin, 2008).

This report presents results for the first of these approaches, exploring historical data in order to describe the spread of the Asian honey bee (AHB; *Apis cerana*) in Australia and to estimate spread rates.

An analysis of the spatial and temporal patterns of an incursion is valuable in that it can yield important information about the species that may be used to predict future spread as well as in guiding management decisions.

Estimating spread based on historical data has been advocated as a more practical approach to estimating spread rates and predicting future spread compared to spread modelling (Hastings et al., 2005). Nevertheless, there are several limitations that need to be kept in mind. Firstly, in very recent introduction/invasions, historical time-space data may not yet be available. Secondly, the assumption that future rate of spread will be the same as past rate of spread may not be valid in all cases (Liebhold & Tobin, 2008).

Historical data can be used to estimate a rate of spread, which can then be used to predict future spread. There are several ways of calculating the rate of spread from historical data. The simplest is a distance regression, which is based on the time that a species was first detected followed by a series of sampling points. A regression of the distance between each sampling point and the origin can then yield a rate of spread (Gilbert & Liebhold, 2010). Other methods include interpreting the cumulative number of detections of a species (Hastings et al., 2005) as well as area-based methods (e.g. square root area regression and boundary displacement; Gilbert, 2010}.

Gilbert & Liebhold (2010) found that the distance regression is the most robust method for estimating spread in a range of circumstances (such as small sample sizes and irregularly shaped invaded area), and so this method will be applied here.

Two previous studies have analysed the spread of AHB in Australia: Skelton et al. (2009) produced a poster detailing their results, and Davis (2011) wrote an unpublished Masters thesis analysing AHB spread in Australia. However, it needs to be noted here that data available to Ms. Davis was incomplete, and so it was imperative to repeat her analysis. Findings of both studies will be compared with the current findings.

This report aimed to fulfil AG3C, QG2C & QG2D of the Asian honey bee (AHB) Transition to Management (T2M) Plan, i.e. to "undertake a spatial analysis of the current AHB infestation to guide future surveillance activities” and to “undertake spread analysis of current AHB infestation to guide future management strategies”.

Specifically, it aimed to conduct a descriptive spatial analysis based on historical data (2007 to 2012), in order to:

- Describe the spread of AHB between 2007 and 2012 in terms of nest and swarm numbers, distance from original point of incursion, and increase in the known infested area over time.
- Explore the rate of spread and swarming capabilities.
- Determine any relationships between the number of detections, distance and area with staff numbers, public reports and meteorological variables.
- Describe seasonal variation in detections and its potential causes.

Methods

Data source

All data was sourced from BioSIRT, Biosecurity Queensland’s database for any detection of AHB nests, swarms and foragers. Specifically, data gathered included the date and location of each detection (including geographic coordinates for mapping purposes as well as habitat type).

Different time periods were used for different analyses:

The overall description of the spread (current situation, nest and swarm numbers over time, staff levels) covers all detections between May 2007 and 30th October 2012.

Data for spatial analyses including distances between nests, swarms, and from Cairns Port covers all detections between May 2007 and 30th June 2012.

Analyses

The number of nests and swarms detected between May 2007 and October 2012 was graphed over time, using both new detections per month as well as cumulative numbers.

The relationship between the number of new detections (swarms and nests combined, nests only and swarms only) and five meteorological measures was determined using a regression analysis. Meteorological variables were chosen to represent the wet-tropical weather found in North Queensland: daily rainfall (mm), maximum daily temperature (˚C), daily 9am humidity (%), daily evaporation (mm) and daily sunshine hours. In addition, to determine a lag-effect, the number of detections was also correlated with the same five meteorological variables for the month prior to the detection. The meteorological variables were sourced from the Bureau of Meteorology (www.bom.gov.au) and downloaded as averages for each month between January 2010 and October 2012. Detections prior to 2010 were excluded form this analysis due to comparatively low new monthly detection numbers that would have skewed the data.

The relationship between staff levels and the number of detections (nests and swarms combined) per month was also determined using a regression analysis. In addition, the relationship between differences in staff levels from one month to the next with the differences in maximum distance from Cairns Port between months was determined using a regression analysis.

In addition, the relationship between the number of public reports of bees and the number of detections per month was explored. The number of public reports of bees per month was sourced from the Queensland Government Call Centre Service. Public reports were divided into total number of reports relating to any bee enquiry, and the total number of reports relating specifically to suspect bees.

Spread

Spread rates were explored in several ways, including distance regression, infested area expansion, and swarming distance estimations.

For the distance regression, the distance of any nest and swarm to the point of origin of the AHB incursion (the Cairns Port where the first nest was detected in May 2007 – 16.94611S, 145.76935E) was measured using ESRI ArcGIS software (Version 10.5) and plotted. A line was then generated that connected the point of origin with the furthest-most detection found. The slope of this line estimated the maximum possible rate of spread of AHB between May 2007 and October 2012.

For the square root area regression, minimum convex polygons were drawn around the furthest-most detection points for each 6-monthly period since May 2007, using ArcGIS. These included calendar-year periods (January to June, and July to December) as well as wet/dry season periods (dry season: May to October; wet season: November to April). The square root of the invaded area, calculated from the minimum convex polygons, was then plotted and regressed over time to estimate the rate of spread.

To gain an understanding of possible swarming distances, the distances between any nest and its nearest known existing nest, as well as any swarm and its nearest known existing nest, were also made. In addition, the 'swarming capability' of the AHB incursion was explored. Assuming that a single colony can double by splitting (exponential growth) it is possible to calculate how often the first and subsequent colonies had to double to reach the current number of detections. This number of splitting events can then be used to determine how often colonies must have split over time.

All statistical analyses were made using GenStat (14th edition, 2011). Statistical significance was set at $p < 0.05$.

Results

Current situation (October 2012)

Between May 4th 2007 and October 31st 2012, there were 799 detections of *Apis cerana*, including 260 swarms and 539 nests. The known infested area (known infested area) covered 490 685 hectares (October 2012) and extended from near Mossman in the north, to South Johnstone in the south, and to near Mareeba in the north-west and Atherton/Malanda in the south-west (Figure 1).

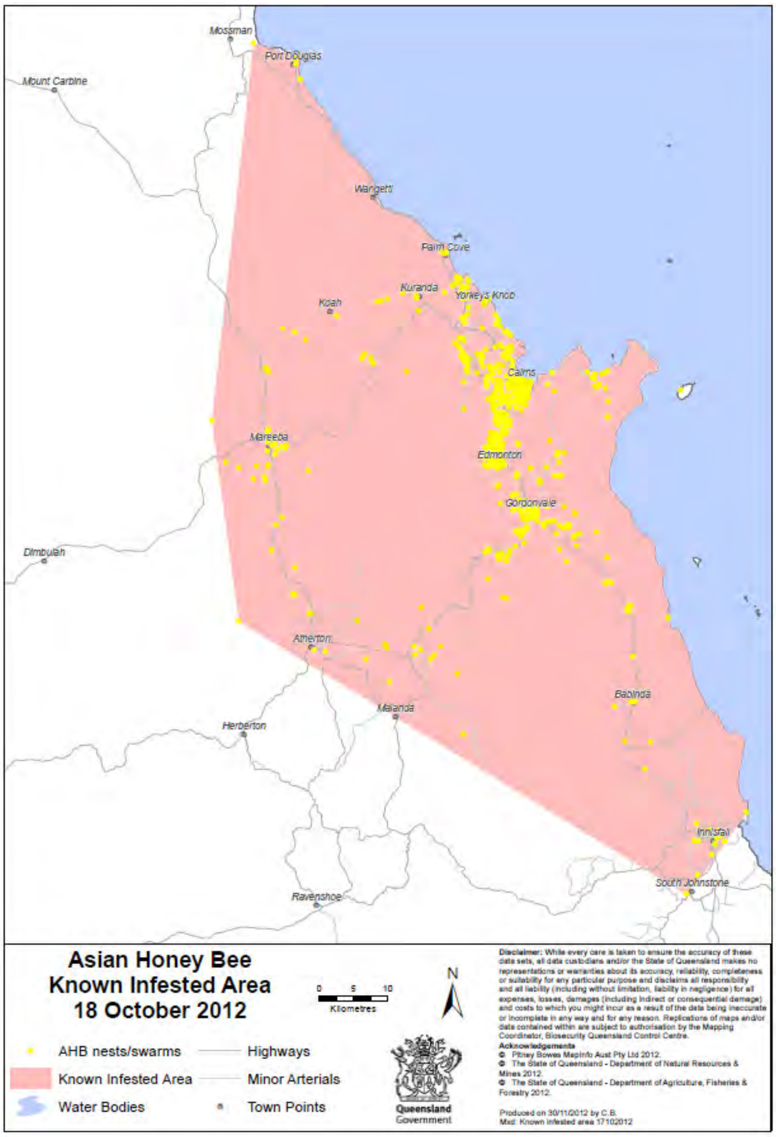


Figure 1 **Map of the AHB known infested area in Cairns, Queensland, Australia; current as of 18th October 2012.**

Nest and swarm numbers over time

The cumulative number of total detections (nests and swarms combined) remained very low between May 2007 and December 2008. It then slightly increased in 2009 and then considerably increased from 2010, with a relatively steady rate of increase thereafter (Figure 2). The steady rate of increase since April 2010 and October 2012 was 21.7 new detections per month (Figure 3).

The number of new detections varied greatly over time, with a maximum of nine new detections per month until December 2009. From January 2010, the number of new detections per month remained more consistent overall but varied between 3 and 47.

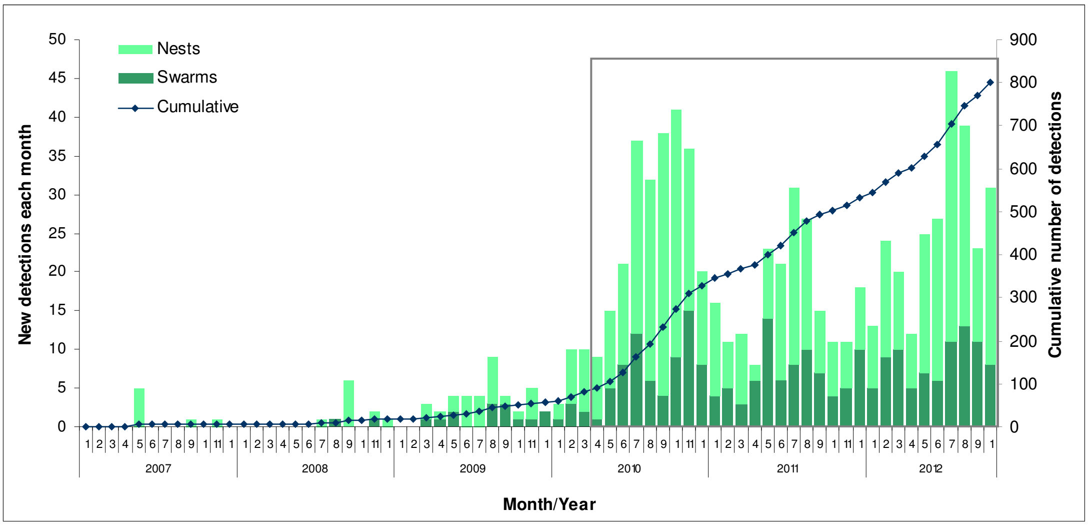


Figure 2 **Stacked bar graph of the number of new AHB swarm and nest detections and the cumulative number of detections over time (2007-2012). Grey box indicates data source for Figure 3 (below).**

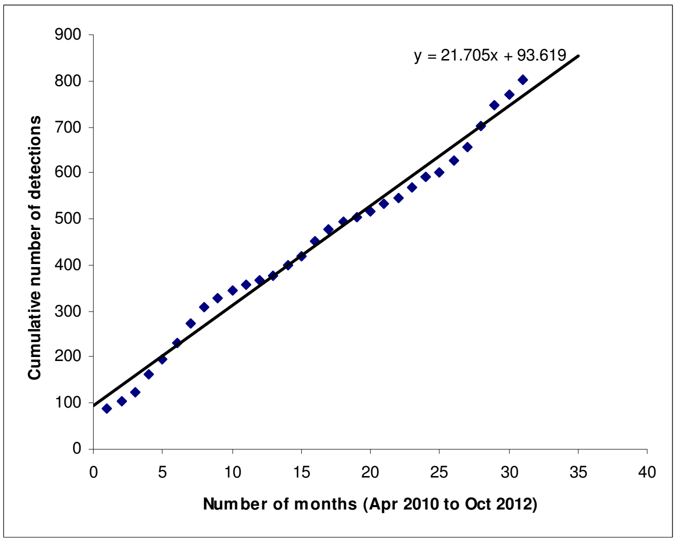


Figure 3 **Cumulative number of detections over time (April 2010 to October 2012) showing a fitted line and its equation to derive the slope (=number of new detections per month)**

The variation in the number of new detections (swarms and nests combined) between 2010 and 2012 was significantly, negatively correlated with monthly rainfall, average daily maximum temperature and average daily 9am humidity (statistical results can be found in Appendix 1).

The number of new detections was also significantly, negatively correlated with the average rainfall in the month prior as well as with average maximum temperature in the month prior, i.e. the hotter and wetter the month, the fewer detections were made in the following month.

The relationship between meteorological variables and detections was mainly driven by nest detections – between 2010 and 2012 the number of nest detections was significantly, negatively correlated with monthly rainfall, monthly rainfall in the month prior, average daily maximum temperature, average daily maximum temperature in the month prior, and average daily 9am humidity, and average evaporation in the month prior (Appendix 1).

Similarly, the number of swarm detections was significantly, negatively correlated with monthly rainfall, monthly rainfall in the month prior, and average daily maximum temperature in the month prior (Appendix 1).

The number of detections (swarms and nests combined, nests only and swarms only) was not correlated with the number of public reports received in the same month. However, the total number of detections and the number of nests detected were correlated with staff numbers - the higher the staff levels, the more nests were detected (Appendix 1).

Distance of nest location from Cairns Port over time

The maximum distance that nests were detected from the Cairns Port increased very little until mid-2008, when nest distance started to increase in a step-wise fashion until April 2010, after which distances remained relatively steady (Figure 4).

Differences in staff levels were not correlated with differences in distance from Cairns Port ($F=0.11$, $p>0.05$; Figure 4).

Using the distances from Cairns Port of all detected nests and swarms (Figure 5), the average rate of spread from was calculated at 240m/month for nests (slope b=8.0268, i.e. 8m/day) and 300m/month for swarms (slope b=10.001, i.e. 10m/day). The maximum possible rate of spread from this data was 1863m/month (slope b=62.125, i.e. 62m/day; Figure 5).

Plotting the maximum rate of spread (1.86km/month) as concentric circles for each year following the first detection, as well as the actual known infested area for the same years, shows a mismatch between the two (Figure 6). The actual spread was much slower and seemed to spread south and west more so than north (Figure 6).

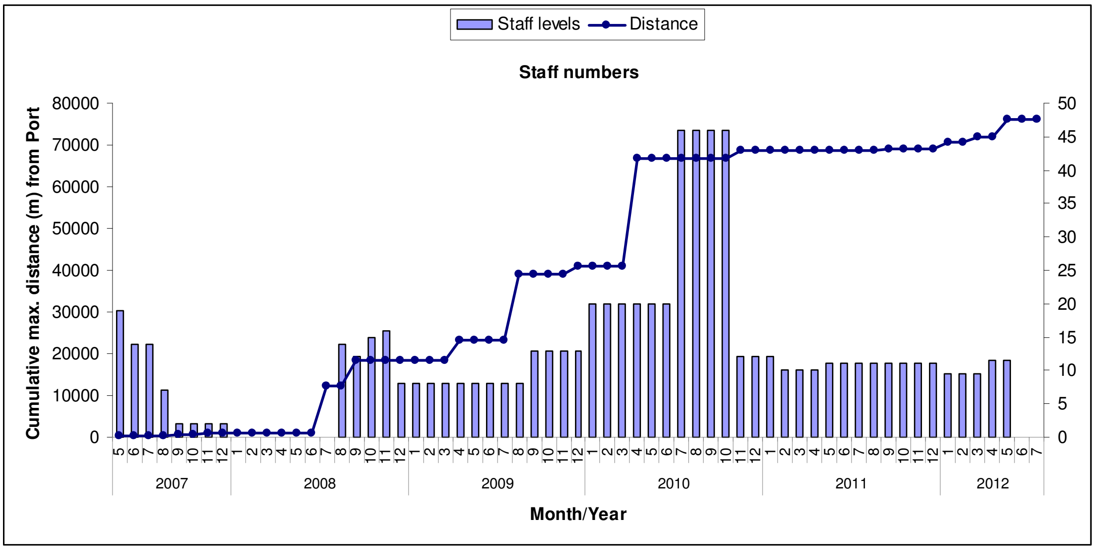


Figure 4 Maximum distance (meters) of nest detections from the Cairns Port (monthly increments) from 2007 to 2012. Also shown are AHB team staff numbers.

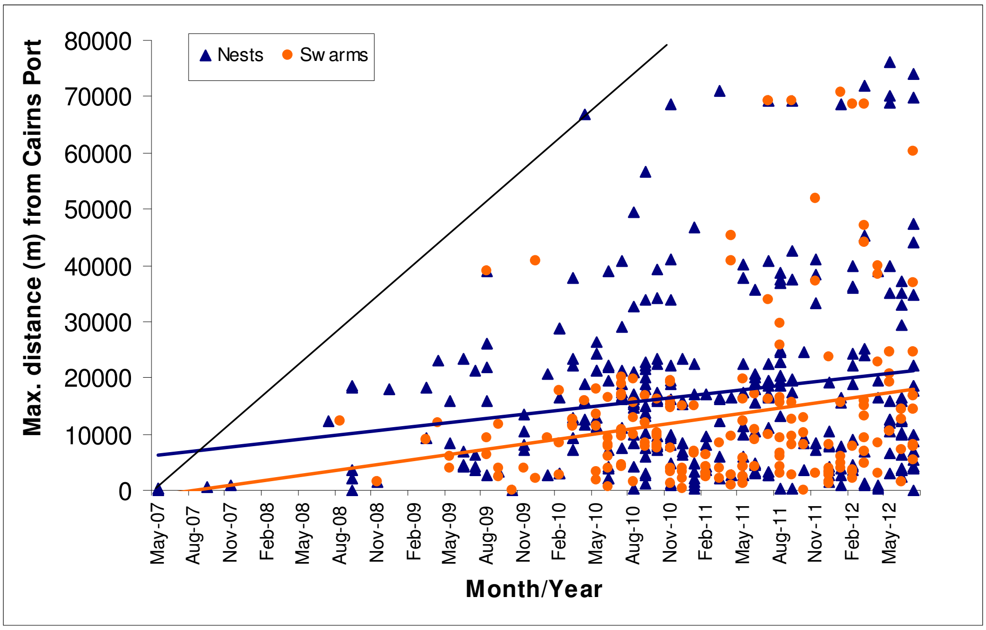


Figure 5 Distance (meters) from the Cairns Port of nest detections (blue triangles) and swarm detections (orange circles) from 2007 to 2012. Blue line indicates average rate of spread based on nest detections, orange line depicts average rate of spread based on swarm detections, black line connects the maximum potential level of spread.

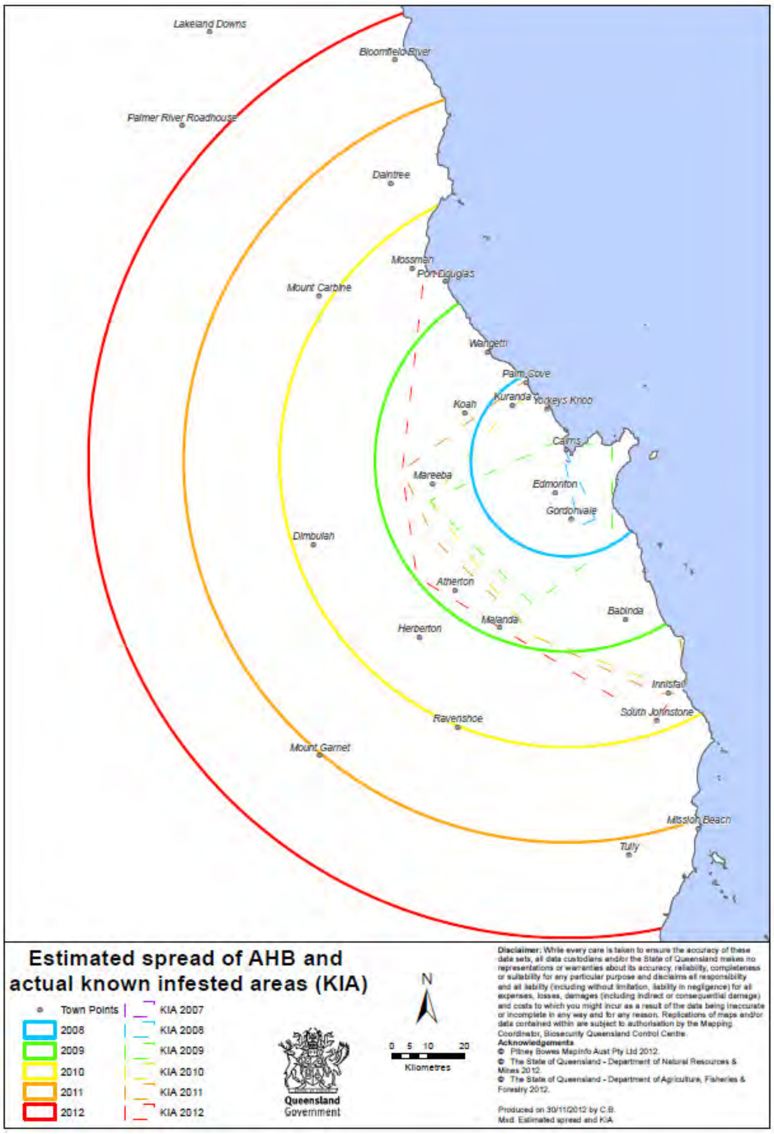
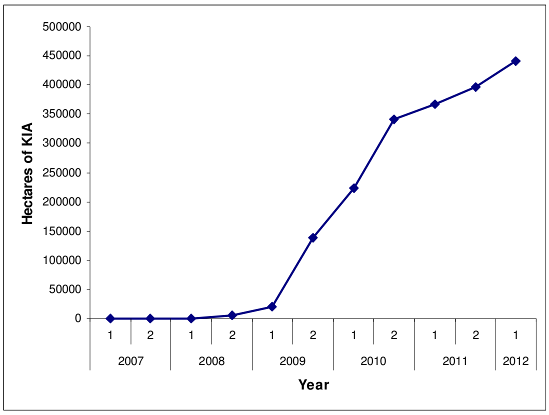
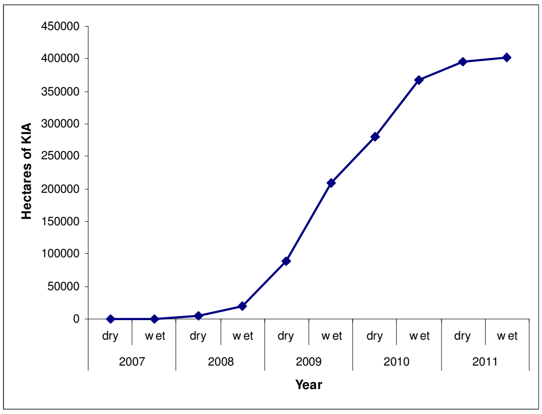


Figure 6 **Actual versus estimated spread of AHB in Queensland, Australia. Stippled lines indicate the actual spread of the known infested area until October 2012; solid circles indicate the estimated spread of 1.86km/month for each year between 2008 (12 months after incursion) and 2012 (60 months after incursion).**

Expansion of known infested area over time

The size of the known infested area remained relatively small (<21000 Ha) from 2007 until the first half of 2009, when it started to increase more quickly up to late 2010 (Figure 7a&b). From early 2011, the rate of increase of the known infested area slowed down but the known infested area continued to increase to 440194 Ha in June 2012 (Figure 7a&b).





a) b)

Figure 7 **Maximum area (hectares) covered by the AHB known infested area in 6-mothly steps between 2007 and 2012; (a) 1 – first half of the year (January to June); 2 – second half of the year (July to December); (b) dry season (May to October) and wet season (November to April).**

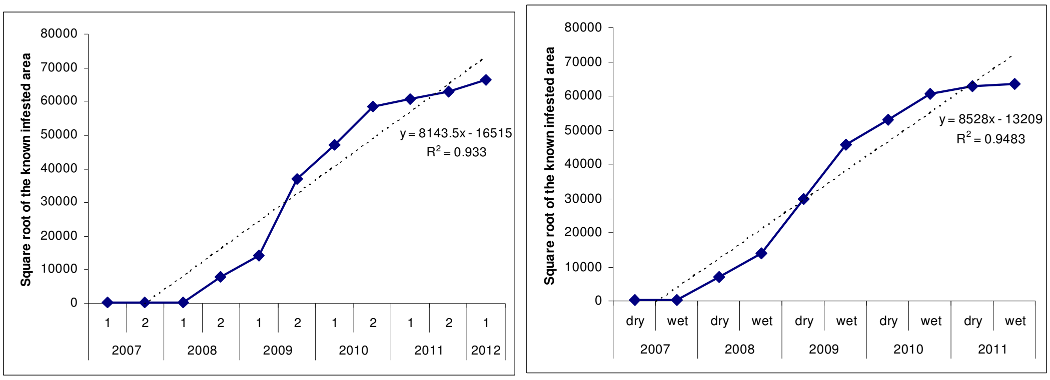
To determine a linear rate of spread from the size of the know infested area, the square root of the area was plotted for each 6-monthly time step (following the methods in Gilbert & Liebhold, 2010) for both Jan-Jun/Jul-Dec periods as well as the wet/dry periods, and a linear as well as logistic (s-shaped) regression was fitted to determine the slope (=rate of spread based on area increase).

When using calendar-year time periods the pattern was very similar to that using wet/dry seasons (Figure 7 & 8). The wet/dry seasons showed a slightly better fit in a linear regression (r^2=0.948 vs. r^2=0.933) as well as in a logistic regression (r^2=0.998 vs. r^2=0.993). The logistic curve showed a very close fit with the data, indicating an initial slow rate of spread (2007 and early 2008), followed by a fast rate of spread (mid-2008 to late 2010) with a decreasing rate of spread after late 2010 (Figure 7 & 8).

The three phases of increase in the known infested area showed distinctly different rates of increase (for calendar-year time periods): 686 Ha/month between 2007 and June 2009; 13395 Ha/month between January 2009 and December 2010; and 5450 Ha/month between July 2010 and June 2012. By far the steepest increase was found between early 2009 and late 2010 (Figure 7 & 8).

When plotting the square root of the area over time, a linear measure of spread can be determined. Using the wet/dry season data, the average spread rate (based on the linear regression) was 1.42km/month (slope *b*=8528, i.e. 8528m/6-months time-step; Figure 8).

The rates of spread in the three distinct phases were: early (April 2007 to September 2008) – 551m/month (slope *b*=3306.6, i.e. 3306.6m per 6 months); middle (October 2008 to September 2010) – 2220m/month (slope *b*=13320, i.e. 13320m per 6 months); and recent (October 2010 to March 2012) – 230m/month (slope *b*=1381, i.e. 1381m per 6 months).



a) **b)**

Figure 8 **Square root of the maximum area covered by the AHB known infested area in 6-mothly steps between 2007 and 2012; (a) 1 – first half of the year (January to June); 2 – second half of the year (July to December); (b) dry season (May to October) and wet season (November to April). The stippled line depicts a linear regression; the regression equation is given underneath the line.**

The largest increase in known infested area relative to its previous size (6 months prior) occurred during 2008, when the size of the known infested area increased by over 400 times (Figure 9). Subsequent increases were never any larger than 5 times its previous size (6 months prior).

The patterns of increase as shown by polygons drawn around the furthest detections (Figure 9) differ only slightly between January-July periods and wet/dry periods and mostly show large jumps to the west and south in 2009 and 2010, respectively.

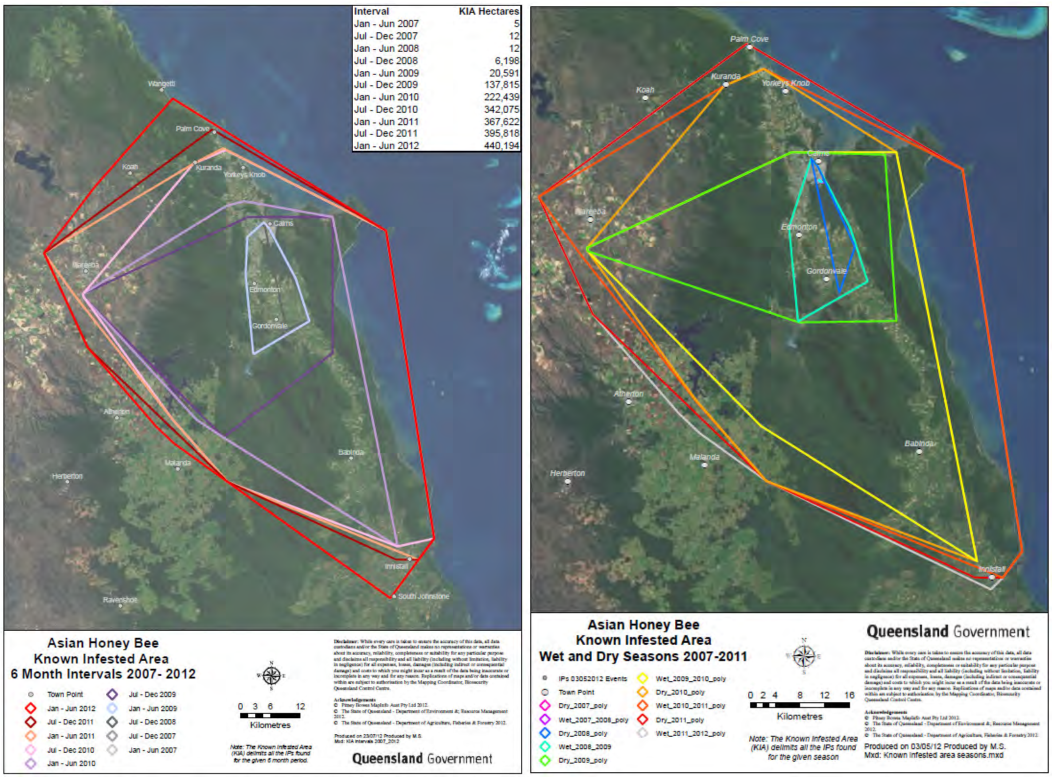


Figure 9 **Expansion of the AHB Known Infested Area (known infested area) between 2007 and 2012 in 6-monthly steps (a) and in 6-monthly steps that are in sync with the tropical wet and dry seasons (b)**

Distance of spread

Under the assumption that new nests and swarms likely originated from the nearest (undiscovered) existing nest, one can measure the distances between any two nearest nests to gain an estimate of how far a colony may travel during reproductive swarming. Similarly, if a new swarm is assumed to originate from the nearest (undiscovered) existing nest, then measuring distances between a new swarm and the nearest known nest may give an indication of swarming distances.

Given that locations of undiscovered nests are unknown, one could measure either the distance to the nearest nests found prior to detection of the swarm in question, or the distance to the nearest nest that was found after the swarm detection. The nest found prior to the swarm detection would have been destroyed upon positive identification of AHB, and so would be unlikely to have been the origin of the swarm in question. It is more likely that the swarm came from a nest that was undiscovered at the time of swarm capture, but that would have been found after the swarm was destroyed. Therefore, this latter distance was used for the analyses.

Estimate of swarming distances

Distances between detected swarms and nearest existing nests are highly left skewed (i.e. mostly, swarms are close to nests with very few instances where swarms where far away from its nearest nest; Figure 11). Therefore, median distances are more informative than average distances.

The median distance between detected swarms and nearest existing nests was 462.1m, with a minimum of zero meters (the swarm was found in the same place as the nest) and a maximum of 63.1km.

50% of swarms were found within 500m of an existing nest, 75% were found within 1000m of an existing nest, and 95% were found within 5000m of an existing nest. There were 12 instances (5% of all cases) where swarms were found further than 5000m from an existing nest.

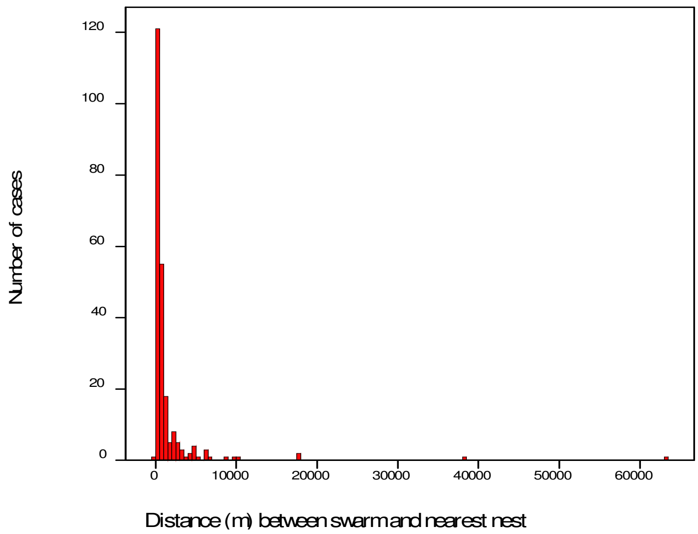


Figure 10 **Histogram of swarm-to-nearest-nest distances (m) showing highly left-skewed data. Median = 462.1m.**

Swarming capability

Assuming that a single colony can double by splitting (exponential growth), given a population size of 799, colonies had to double 9.62 times (i.e. $2^{9.64} \approx 799$). Thus, 9.64 splitting events must have occurred to reach a size of 799.

799 detections were made between May 4th 2007 and October 31st 2012, which equals 2007 days. Given 9.64 splitting events over 2007 days, colonies must have split every 208.2 days (i.e. every 6-7 months).

Discussion

The descriptive spatial analysis showed that the number of detections, the distance from Cairns Port and the overall area of the known infested area have increased substantially since 2007. Although the number of new detections was still rising at a steady rate of approximately 22 new nests per month, the data also showed a general decline in the rate of spread both for the distance from Cairns Port as well as for the total area of the known infested area since 2010. Whether this decline in the rate of spread is an indication of an actual decline in spread, or a result of decreasing surveillance over an ever-increasing area needs to be discussed (see below).

Nest and swarm numbers over time

Apart from the general increase in numbers of detections over time, great variation in the number of detections was apparent in the data (e.g. Figure 2). The variation in detections was in part linked to meteorological variables, specifically total rainfall, temperature and humidity. Particularly interesting was a very strong correlation between numbers of detections and rainfall and temperature in the month prior. Detections were also positively correlated with staff numbers, but, surprisingly, not with the number of public reports received.

The relationship between detections and meteorological variables could indicate that (1) bee numbers are influenced by weather (i.e. high temperature and rainfall results in reduced bee activity), or (2) bee numbers remain the same but field staff cannot find bees either due to changed timing of bee foraging during hot weather, and/or due to due to reduced visibility in the rain.

Some detections were made even during very wet months (Figure 2). It needs to be noted here that the variation in the data is large – months with little or no rain did not necessarily result in large numbers of detections. However, months with a lot of rain never yielded many detections (Figure 2).

However, the significant, negative correlation between monthly new detections and rainfall, humidity and temperature does indicate that detections are seasonal, with more nests and swarms detected in the 'dry season' (lower temperature, rainfall and humidity) than in the 'wet season' (Figure 2).

Average maximum daily temperatures in the month prior showed a very strong, negative relationship with the number of detections (swarms & nests, nests only and swarms only; Table 1). Temperature should not affect bee visibility so it may be argued that bee numbers are higher during colder months and lower during warmer months. Alternatively, bee numbers may remain the same, but bees may forage very early and very late in the day, which may result in lower detections by field staff due to their working hours.

A correlation between staff numbers and detections is not surprising and can be explained by the greater surveillance effort possible with greater staff numbers.

However, it is surprising that the number of public calls was not related to the number of detections. The efficacy of public reporting will be analysed in a separate report.

Distance from Cairns Port

The distance from Cairns Port increased over time, as expected. However, the distance from Cairns Port has remained relatively steady since April 2010 (Figure 3). This may be due to the fact that (1) the spread has slowed, or (2) that it has come across climatic or other boundaries (e.g. the western edge may be too dry), or (3) it is an artefact of reduced surveillance along the increasing edge of the known infested area.

The maximum possible rate of spread based on nest and swarm distances from Cairns Port was calculated to be 1.86km/month (Figure 5). This rate is slightly higher than Skelton et al. (2009)'s 1.67km/month.

Overlaying the estimated maximum rate of spread and the actual known infested area for each year after the initial detection shows a great discrepancy between the two (Figure 6). The known infested area did not spread nearly as far or as fast as predicted by the estimated rate of spread. The actual spread also does not appear to move in concentric circles, but rather it appears that the known infested area spread south and west more so than north (Figure 6). It also appears as though the westerly spread has slowed (Figure 6). This apparent slowing of the spread is also suggested by the expansion of the known infested area (see below).

Major increases in distance from Cairns Port ('jumps') do not seem to be restricted to the wet or dry season. Some jumps occurred during the dry seasons (July and September 2008; August 2009) whereas some jumps occurred during the late wet season (April 2009; April 2010; Figure 3).

Increases in staff levels were not associated with increases in distance from Cairns Port. In particular, a doubling of staff levels in July 2010 did not result in any increase of distance from Cairns Port (Figure 3).

It is interesting to note that increased staff levels increased the number of detections but not the distance at which these were found.

Expansion of known infested area

The area of the known infested area increased to 440194 Ha by June 2012, five years after the first detection. Interestingly, there were three distinct phases with different rates of increase (Figures 7 & 8). The average rate of spread from this area data was estimated to be 1.42km/month, which is slightly less than previous estimates. However, between 2008 and 2010, the known infested area increased substantially, with an estimated rate of spread, based on the square root of the known infested area, was 2.22km/month. More recently, however, the rate of spread seemed to have slowed to 0.23km/month. This slowing of spread is also reflected in the distance from Cairns Port.

As mentioned previously, the question remains whether the rate of spread has indeed slowed, or whether this slowing spread is due to other factors, such as AHB reaching climatic or other boundaries, or whether it is an artefact of reduced surveillance along the increasing edge of the known infested area.

Despite reduced surveillance by AHB field staff, public reporting should not be affected by the increasing distance from Cairns. However, locations on the edge (especially the western and northern edge) are increasingly less populated, and so public reports may also be less frequent.

Distance of spread

Swarming distances were estimated from the distances of swarms and their nearest nests, as well as through calculating a swarming capability.

The median distance between any swarm and its nearest nest was 462m. Most swarms (75%) were found within 1000m of a nest, and the majority of swarms (95%) were found within 5000m of a nest. Five percent of swarms were found at distances substantially greater than 5000m, and these may be assumed to have been inadvertently transported by humans. Although dispersal/migration distances are unknown for AHB (*Apis cerana*), the presented data give some indication on possible dispersal distances (<5km).

In order to reach nearly 800 detections by October 2012, colonies had to split 9.62 times, which can be translated into a splitting event occurring every 6-7 months, or twice a year. This is similar to other estimates of how often AHB may swarm in the tropics (reviewed in Hepburn, 2011).

Conclusion

A descriptive spatial analysis based on historical data can be used to predict possible future spread and guide future surveillance and management decisions. It may also be used to determine gaps in knowledge and data, and as input for computer simulation modelling. Particularly interesting would be a validation of the current results, using data available in the future.

Although spread rates can and have been estimated from historical data, they may not be accurate due to the fact that the assumption of a steady, non-changing rate of spread is unlikely to be true. This can be seen in the current results. When estimating an average spread rate from 2007-2012 data and overlaying it with the current extent of the known infested area, it becomes clear that AHB did not in fact spread at that same rate. This may be due to the rate of spread slowing, or climatic or other barriers being encountered by the AHB population, or it could be an artefact of reduced surveillance in an ever-increasing area of infestation. Further research is necessary to determine which of these processes (if any) may be resulting in a slower rate of spread than predicted.

Appendix 1

Statistical results for linear regression analyses of detections (nests and swarms, nests only, swarms only) between January 2010 and October 2012 versus five meteorological variables (for the same month of detections as well as for the month prior to the detections; total monthly rainfall, and averaged for each month: daily maximum temperature, 9am humidity, daily sunshine hours, daily evaporation), the number of public reports (suspect bees only and total calls received by the call centre), and staff numbers within the Asian honey bee Program). F-probabilities are given for all variables (bold = statistically significant; n.s. – not significantly different), r^2 values are given for statistically significant variables.

Detections	Time period	Variable	p	r^2
Nest & swarms	Same month	Rainfall	**0.009**	**0.171**
		Max temperature	**0.002**	**0.249**
		9am humidity	**0.012**	**0.157**
		Sunshine hours	n.s.	
		Evaporation	n.s.	
		Public reports (suspect bees)	n.s.	
		Public reports (total)	n.s.	
		Staff numbers	**0.010**	**0.164**
	Month prior	Rainfall	**0.001**	**0.263**
		Max temperature	**<0.001**	**0.366**
		9am humidity	n.s.	
		Sunshine hours	n.s.	
		Evaporation	n.s.	
Nests only	Same month	Rainfall	**0.017**	**0.14**
		Max temperature	**0.003**	**0.227**
		9am humidity	**0.014**	**0.148**
		Sunshine hours	n.s.	
		Evaporation	n.s.	
		Public reports (suspect bees)	n.s.	
		Public reports (total)	n.s.	
		Staff numbers	**<0.001**	**0.313**
	Month prior	Rainfall	**0.007**	**0.189**
		Max temperature	**<0.001**	**0.314**
		9am humidity	n.s.	
		Sunshine hours	n.s.	
		Evaporation	**0.033**	**0.114**
Swarms only	Same month	Rainfall	**0.050**	**0.088**
		Max temperature	n.s.	
		9am humidity	n.s.	
		Sunshine hours	n.s.	
		Evaporation	n.s.	
		Public reports (suspect bees)	n.s.	
		Public reports (total)	n.s.	
		Staff numbers	n.s.	
	Month prior	Rainfall	**0.005**	**0.207**
		Max temperature	**0.023**	**0.132**
		9am humidity	n.s.	
		Sunshine hours	n.s.	
		Evaporation	n.s.	

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