Final Report

Understanding and Mitigating the Aggregative Response of the Magpie Goose on Mango Orchards in the Northern Territory

Project leader:

Dr Hamish A. Campbell

Delivery partner:

Research Institute for the Environment and Livelihoods, College of Engineering, IT and Environment, Charles Darwin University

Project code:

MG15005

Project:

Understanding and Mitigating the Aggregative Response of the Magpie Goose on Mango Orchards in the Norther Territory – MG15005

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using the mango research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978 0 7341 4534 5

Published and distributed by: Hort Innovation

Level 8
1 Chifley Square
Sydney NSW 2000

Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Summary

The overarching goal of this project was to provide the Australian mango industry with advice to reduce the impact of the Magpie Goose upon the mango industry in the Northern Territory.

Mangoes are currently the most valuable horticultural product in the Northern Territory (NT), and the territory's production represents almost half of the total Australian production (Australian Mango Industry Association 2019). In 2013, Magpie Geese were identified as a key issue for mango growers through the mango industry small-group process ran under HIA project MG12005. The birds were reported to damage fruits, trees, and irrigation equipment. Consequently, this project was supported and initiated by key industry and government stakeholders (NT Department of Primary Industries and Resources (DPIR), NT Department of Environment and Natural Resources (DENR), NT Parks and Wildlife Commission (PWC), NT Farmers Association (NTFA), Australian Mango Industry Association (AMIA)).

The project comprised two core components; 1) an ecological study of Magpie Geese to better understand their behaviour on and around mango orchards, and 2) an assessment of the effectiveness of various adverse stimuli to reduce bird density on orchards and bird-crop interactions. These complementary approaches were necessary to:

- Establish the extent of the conflict reported by mango growers,
- Identify the underlying drivers of Magpie Goose distribution and abundance on mango orchards, and
- Provide management recommendations suited to the scale of the conflict and biology of the species

Field work for this project was undertaken during the 2016, 2017 and 2018 mango seasons in the Greater Darwin Region. Satellite telemetry of individual Magpie Geese and molecular analyses of stomach contents were used to investigate how habitat resources influence Magpie Goose behaviour. Management approaches evaluated included: 1) acoustic deterrents, 2) visual deterrents, and 3) chemical deterrents.

Key research outputs:

- Small groups forums conducted with mango growers of the Darwin region
- Dissemination of research preliminary findings at industry meetings, conferences and publications (AMIA, NTFA)
- Fact sheet of recommendations for mango growers (to be completed)

Key research outcomes:

- New ecological knowledge on Magpie Geese that can be used to design and implement broad spatial scale management strategies across the region.
- Practical recommendations to reduce the impact of Magpie Goose on the mango crop.

Keywords

Magpie Geese; mangoes; pest management; behavioural ecology; animal movement ecology

Introduction

The Magpie Goose (*Anseranas semipalmata*) is a taxonomically distinct waterbird protected by law but is considered a pest species by mango growers in northern Australia. Anecdotal evidence suggested that mango growers lose 10-15% of their crops to Magpie Geese. If this level of damage is consistent throughout the Darwin growing region, the impact of Magpie Geese could represent $2m per year to the NT mango industry (Hunt 2016). This conflict between farmers and Magpie Geese is not new; previous studies have highlighted the potential effects on Magpie Geese on rice crops (Frith and Davies 1961), and fruit crops (e.g., rambutans, melons and mangoes) (Whitehead 1991) since the early 1950s. The conflict with farmers is often exacerbated when fruit development coincides with the late dry season as natural resources for Magpie Geese are scarce (Delaney et al. 2009). Despite a number of studies on the Magpie Goose in the Northern Territory, none has addressed specifically the conflict with mango growers.

The impact of birds on agriculture is a global phenomenon involving a range of different species and crops. Further to the complexity of finding appropriate techniques for managing birds, the effectiveness of different approaches vary widely due to: 1) the variation in bird species biology and behaviour, 2) the variability and unpredictability of crop damage; and 3) the social, environmental, and legal implications of management policies and methods (Tracey et al. 2007). For most farmers, conducting pest bird management programs and assessing their efficacy is labour-intensive, time consuming, and costly. The lack of information often leaves farmers with very few resources to address crop-raiding birds on their farms. Knowledge on the behaviour and biology of the pest species is essential for the development of appropriate management plans (Tracey et al. 2007), as well as an understanding the drivers of movements and habitat use (Roshier 2008).

Therefore, this project was designed to provide theoretical and practical knowledge that can be applied to understand Magpie Goose use of mango orchards and better manage their impact upon crops. The first component of this research used satellite telemetry and molecular analyses to provide new, fine-scale information on the ecology and biology of Magpie Goose to evaluate the extent of, and mechanisms behind, Magpie Goose use of mango orchards, the resources they use and the spatial and temporal scales at which they need to be managed. The second component evaluated the application of different management methods and assessed their effectiveness based on bird density, abundance, and time before return to site to provide decision making tools for growers to make informed decisions for implementation of management strategies.

The research team at Charles Darwin University worked in close collaboration with a project advisory committee formed by representing members of the different partner institutions and associations; NT Department of Primary Industries and Resources (DPI), NT Department of Environment and Natural Resources (DENR), NT Parks and Wildlife Commission (PWC), NT Farmers Association (NTFA), Australian Mango Industry Association (AMIA), and Hort Innovation. This committee provided strategic guidance and technical assistance throughout the project. Extensions activities for the project were led by the NT Department of Primary Industries and Resources.

Methodology

The different research components for this project were conducted on and around mango orchards of the Greater Darwin Region. More than a hundred mango farms are found in this area, most of which reported having issues with Magpie Geese during an initial consultation with local mango growers at the start of this project (Figure 1). All procedures involving use of wild Magpie Geese were approved by Charles Darwin University Animal Research Ethics Committee (Permit # A16016) and all relevant permits from the NT Parks and Wildlife Commission were obtained.

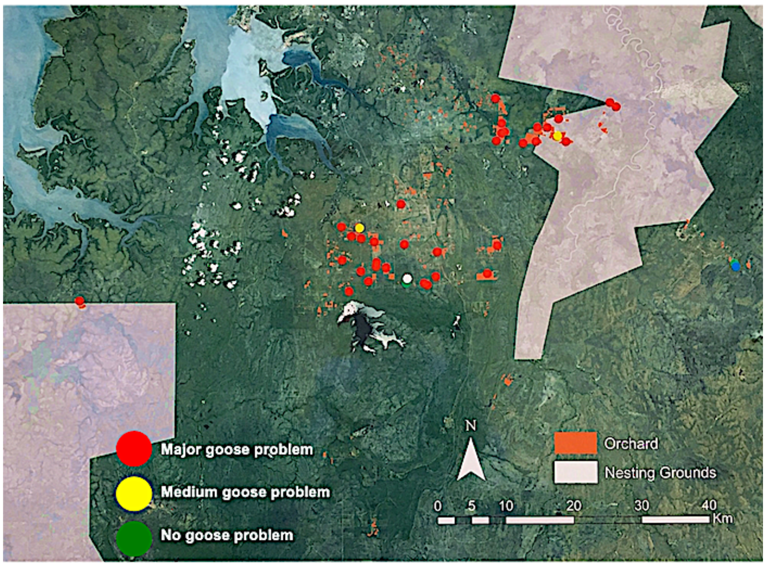


Figure 1. Extension meeting workshop conducted at Acacia Hills, NT on 21 April 2016. Using small-group discussions, this process allowed the research team to better understand the conflict between mango growers and Magpie Geese. Each group comprised a member from project advisory committee (here, Greg Owens from NT Farmers Association) to facilitate discussion and record key information (left; photo: Warren Hunt). Growers also participated in an interactive activity to indicate the level of conflict with Magpie Geese on their farm (right; farm spatial data: DPIR, nesting ground spatial data: DENR).

Research Component 1: Magpie Goose Ecology & Behaviour

Magpie Goose GPS Tracking

Magpie Geese were captured using cage traps at several locations within the areas of Acacia Hills, Lambells Lagoon and Berry Springs. All trapped geese were weighed, measured, and fitted with numbered steel leg bands provided by the Australian Bird and Bat Banding Scheme (ABBBS). A subset of individuals was fitted with different GPS devices for tracking over different periods of time (seasonal or annual) (Figure 2). Different devices were programmed to record goose locations every 10, 30 and 60 minutes to provide high resolution data through time and space. These data allowed determination when and where individuals were, calculating the duration of time spent by individuals at these locations, distance and speed at which they travel, and size of the area that they utilise (home range) on different periodic bases (e.g., daily, weekly, monthly, annually).

Figure 2. Magpie Goose individual taking flight with a GPS neck collar tracking device and ABBBS leg band (photo: Hamish Campbell).

Magpie Goose diet analyses

Magpie Goose carcasses were collected opportunistically during hunting activities that were conducted independently of this study. Amenable hunters provided Magpie Goose carcasses at different sites (farms or hunting reserves) between October 2018 and January 2019. These carcasses were dissected in laboratory and contents from the gastrointestinal tract (GIT) were sampled. Next-generation high throughput

DNA sequencing was used to analyse the extracted GIT contents (Figure 3). This technique allowed identifying the food items consumed by the Magpie Geese through comparing DNA sequences detected in the GIT samples against a reference library to provide a taxonomic assignment. Two PCR assays targeting chloroplast genes were used for this quantification: rbcL (Poinar et al. 1998) and trnL (Taberlet et al. 2007). These data allowed evaluating Magpie Goose's reliance on mango as a food resource as well as comparing variation in food sources across locations and times.

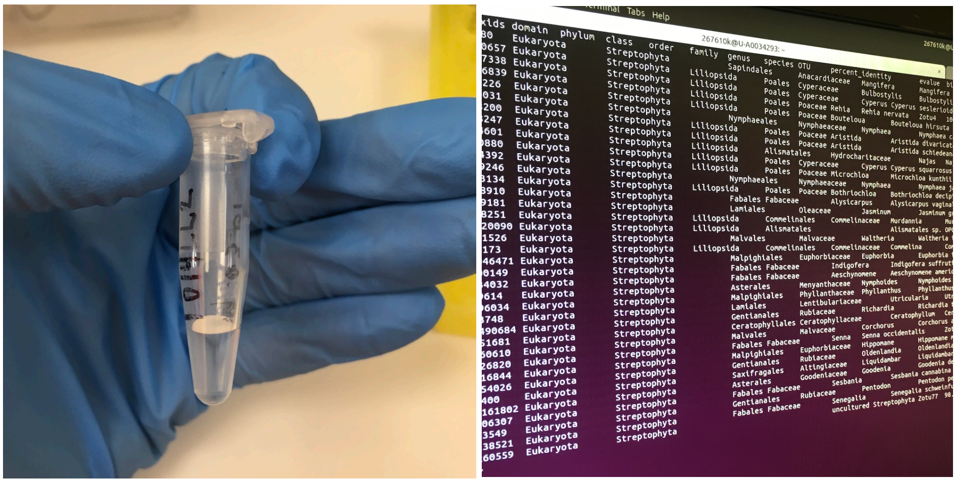


Figure 3. Extracted DNA from Magpie Goose gastrointestinal contents (left) and taxonomic assignment obtained from the DNA metabarcoding process (right) (photos: Amélie Corriveau).

Research Component #2: Evaluation of adverse stimuli deterrents

Auditory Deterrents

We evaluated the effectiveness of a long-range acoustic device (LRAD; LRAD Corporation 2019) that played a variety of pre-programmed sounds (Figure 4). These are similar devices by those used by police to disperse crowds. The LRAD device was mounted on a quad bike and the geese dispersed from the orchard by directing the speaker from the LRAD upon them. Sounds broadcasted, routes and schedules of the scaring was varied each day to ensure the birds did not become habituated. Effectiveness of the device was determined using damage assessments and bird counts.

Figure 4. Long-range acoustic device (LRAD) evaluated in this study (photo: Amélie Corriveau).

We also evaluated the effectiveness of a remotely piloted aerial vehicle (drone) as a system for delivery of the acoustic adverse stimuli. These trials were undertaken every morning consecutively for 14 days on a small farm. Different sounds were broadcasted to compare their effectiveness. Effectiveness was measured by comparing the speed at which geese fled the orchard and time elapsed before they returned. We used a medium-sized hexacopter drone (DJI Matrice 600 Pro) outfitted with a purpose designed loudspeaker capable of producing custom sound recordings (Figure 5). This loudspeaker is rated to 80 decibels at 100 meters from the speaker and sounds were broadcasted continuously from the speaker. Drone flights were conducted starting at 7am and each flight path followed the centreline of the long side of the orchard. Flying at an altitude of 15 meters above the ground, the drone was capable of completely clearing the orchard of geese in approximately 5 minutes.

Figure 5. DJI Matrice 600 Pro remotely piloted aircraft mounted with an acoustic broadcasting device (emergency services megafauna) programmed to play a sound frequency that Magpie Geese were patricianly averse to.

To better assess the effectiveness of scaring Magpie Geese as a means to protect fruit, a study was set up where two orchard blocks where compared with- and without- scaring activities. We installed 10 wildlife detection cameras at randomly selected positions across each orchard (Figure 6). The field of view for each camera contained two mango trees and cameras were programmed to record an image every 5 minutes. All cameras were synchronized so all images were taken at the same time. This provided the monitoring of 10 random 10 m^2 plots within the orchard. These data were then used to determine Magpie Goose density per hectare. On one farm, quad bike scaring was conducted by farm employees daily, at sunrise and frequently (20-30 mins) throughout the day. No scaring of any kind was implemented on the other farm. Every fortnight, a fruit damage assessment was undertaken on monitored trees to record potential animal damage.

Figure 6. Wildlife detection camera deployed on one of the two orchards (left) and resulting image from camera showing two Magpie Geese foraging on a mango (right) (photos: Paige Richter).

Chemical deterrents

We assessed the effectiveness of four commercially available deterrents: 1) Chilli Barrier (Resource Bio Management 2019), 2) Scat (Multicrop 2019) – chemical compound aluminium ammonium sulphate based product designed to be dissolved in water and applied to fruits and plants threatened by wildlife, 3) D-ter (Lorac 2019) – another chemical compound aluminium ammonium sulphate based product formulated differently than Scat with similar application methods, and 4) Bird Away (Ensystex 2019) – a gel product using Flame Shield Gel Technology™ designed as an olfactory and visual deterrent preventing birds from entering the area of application. We conducted two different types of trials. The first involved using large piles of mangoes with and without chemical deterrent treatment (Figure 7). The fruit piles were left out in the open and monitored with motion detection cameras. The second type of trial included spraying the mango trees and grass surrounding the trees. Fruits were not sprayed to avoid potential effects to fruits as this remained to be tested separately. Chemicals were applied at the recommended dose, as well as with a concentration two times the recommended dose.

Figure 7. Magpie Geese arriving at a pile of mangoes dipped in chemical adverse deterrent.

Outcomes

Research Component 1: Magpie Goose Ecology & Behaviour

***Note: This section contains preliminary results only as GPS tracking data is still incoming and analyses are still ongoing. Final results for Research Component 1 will be available upon publication of peer-reviewed scientific articles by the research team and thesis by the PhD candidate Amélie Corriveau.*

Magpie Goose movements

A total of 301 Magpie Geese were captured and 93 were tracked using GPS-devices from 20 October 2016 until today (as of May 30, 2019). Tracked birds from the Greater Darwin Region revealed wide ranging movements, extending from Wyndham/Kununnara, WA in the west, to Nhulunbuy, NT in the east, and Katherine, NT in the south (Figure 8). Details about tracking duration, speed and distances moved by Magpie Geese are provided below (Table 1). Some individuals tracking for more than a year returned to the same mango growing area, showing some degree of site fidelity in their dry season site utilisation behaviour.

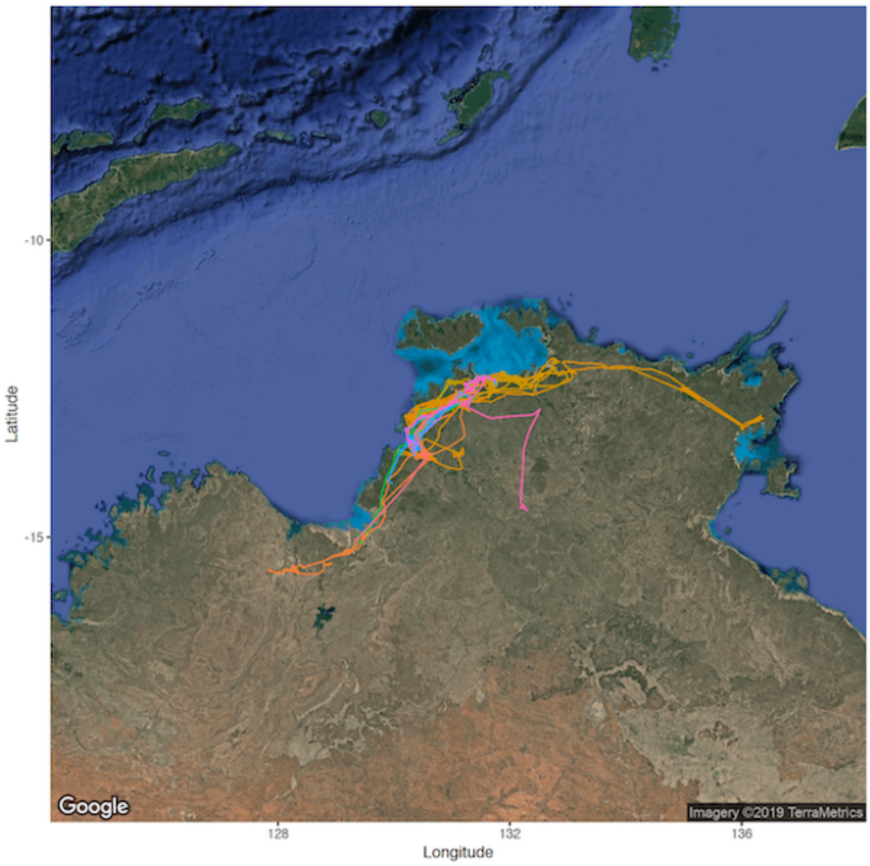


Figure 8. Map showing movements of all Magpie Goose individuals tracked during this study from 2016 to now (30 May 2019).

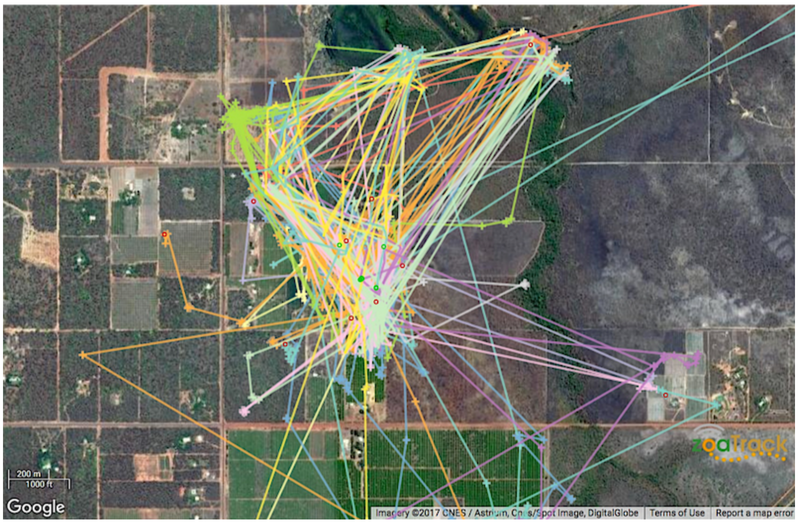
Table 1. Summary of movement metrics calculated from Magpie Goose GPS tracking data (until 30 May 2019).

Variable	Minimum	Mean	Median	Maximum
Tracking duration (day)	<1	52	19	575
Mean speed (km/h)	<1	0.1	0.1	8
Maximum speed (km/h)	<1	2.2	1.1	60
Total distance (km)	<1	1347.7	640.6	5571.18
Daily distance (km) - Annual	<1	8.3	5.1	254.3
Daily distance (km) - Seasonal	<1	6.9	4.4	136.4
Weekly distance (km) - Annual	<1	52.2	36.8	652.1
Weekly distance (km) - Seasonal	<1	39	26	368.1

* **Annual:** n = 74 geese, 3873 goose-days, 646 goose-weeks

* **Seasonal**: n = 74 geese, 2066 goose-days, 382 goose-weeks - October to December inclusively

During the mango season, geese tagged displayed short, often repeated daily movements between areas where they could find water, tall native trees for roosting and feeding areas (Figure 9). In order to quantify habitat use by Magpie Geese, we used a '*hotspot*' analysis (package "recurse" in the R-programming language; Bracis et al. 2018) to determine the number of times and duration of each visit at these locations. The results of this preliminary analysis for one individual showed that this individual visited most often native bushland and orchard blocks, and only visited periodically the water point. The local native bushland was the area where the individual spent the most time compared to other habitats (Figure 10). While displaying regular, local movements, geese were also capable of moving rapidly to a new area within the same region to establish similar movement patterns in a new area providing key resources (Figure 11).



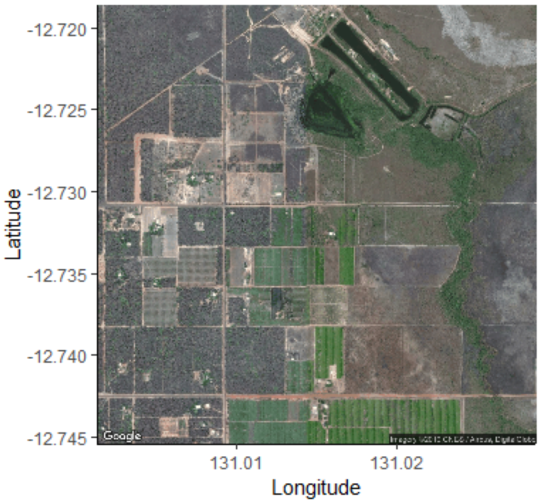
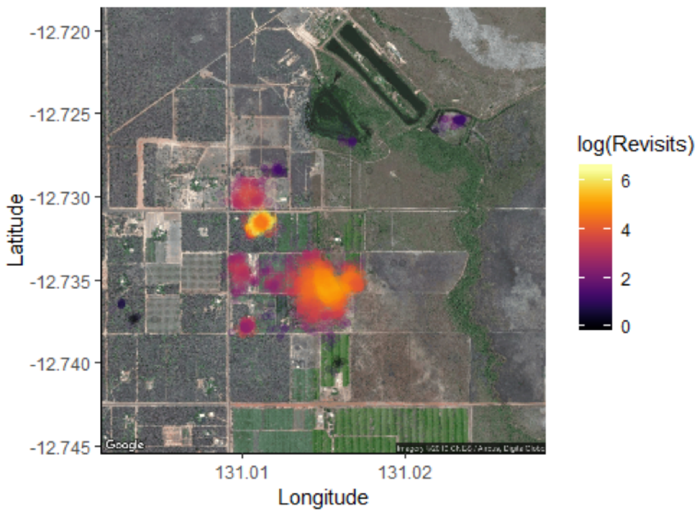


Figure 9. Map showing movements of different Magpie Goose individuals displaying repeated movements in the Berry Springs, NT area during mango season 2016 (left). A blank map of the same area is provided to identify landscape features utilised by individuals (right).



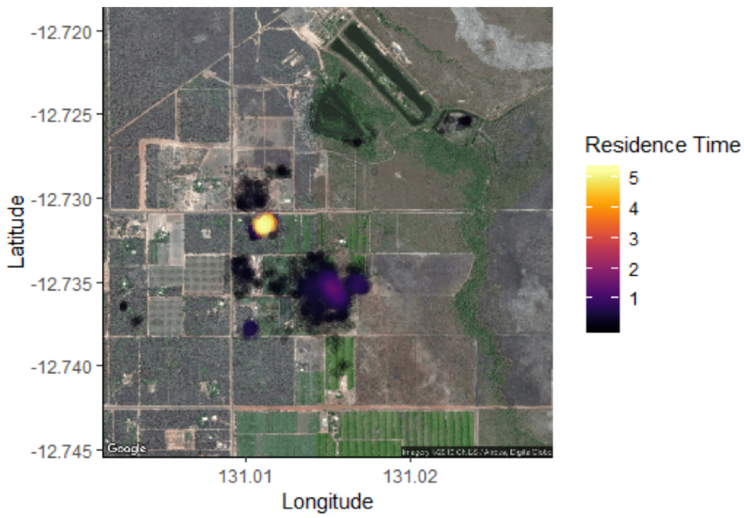


Figure 10. Map showing number of the logarithmically scaled rates of revisitation (left) and number of hours spent (right) by one individual Magpie Goose at different habitats in the Berry Springs, NT area during mango season 2017.

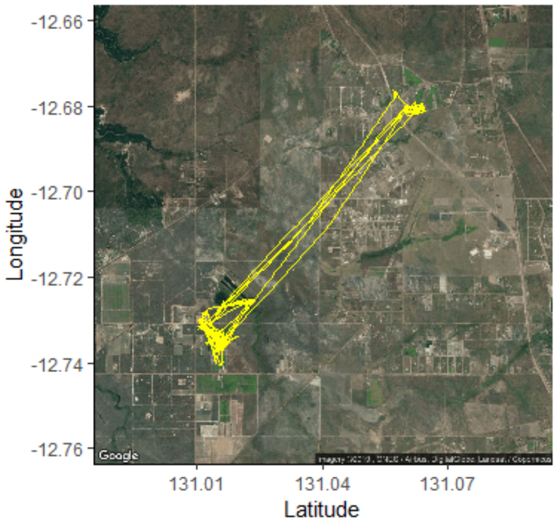


Figure 11. Monthly movements of an individual Magpie Goose moving between 2 different mango growing areas in the Berry Springs region.

Magpie Goose diet analyses

A total of 183 Magpie Goose carcasses were collected across 6 locations throughout the Greater Darwin Region and over 11 weeks of the mango season 2018. From these samples collected, 155 samples were taken through the DNA metabarcoding process. Preliminary results for a subset of samples (n=54) showed that a large number of plant families were detected. The plant families detected most often (% = proportion of samples) using the rbcL assay were: 1) Cyperaceae (sedges; 85%), 2) Poaceae (grasses; 70%), 3) Anacardiaceae (mangoes: 59%), 4) Nymphaeaceae (water lilies; 33%), and 5) Fabaceae (legumes; 31%). The plant families detected most often using the trnL assay were: 1) Poaceae (46%), 2) Anacardiaceae (41%), 3) Fabaceae (31%), 4) Nymphaeaceae (33%), and 5) Asteraceae (flowering plants, daisy family: 15%). The results showed a considerable variation in proportion of plant families detected between the different locations (Figure 12).

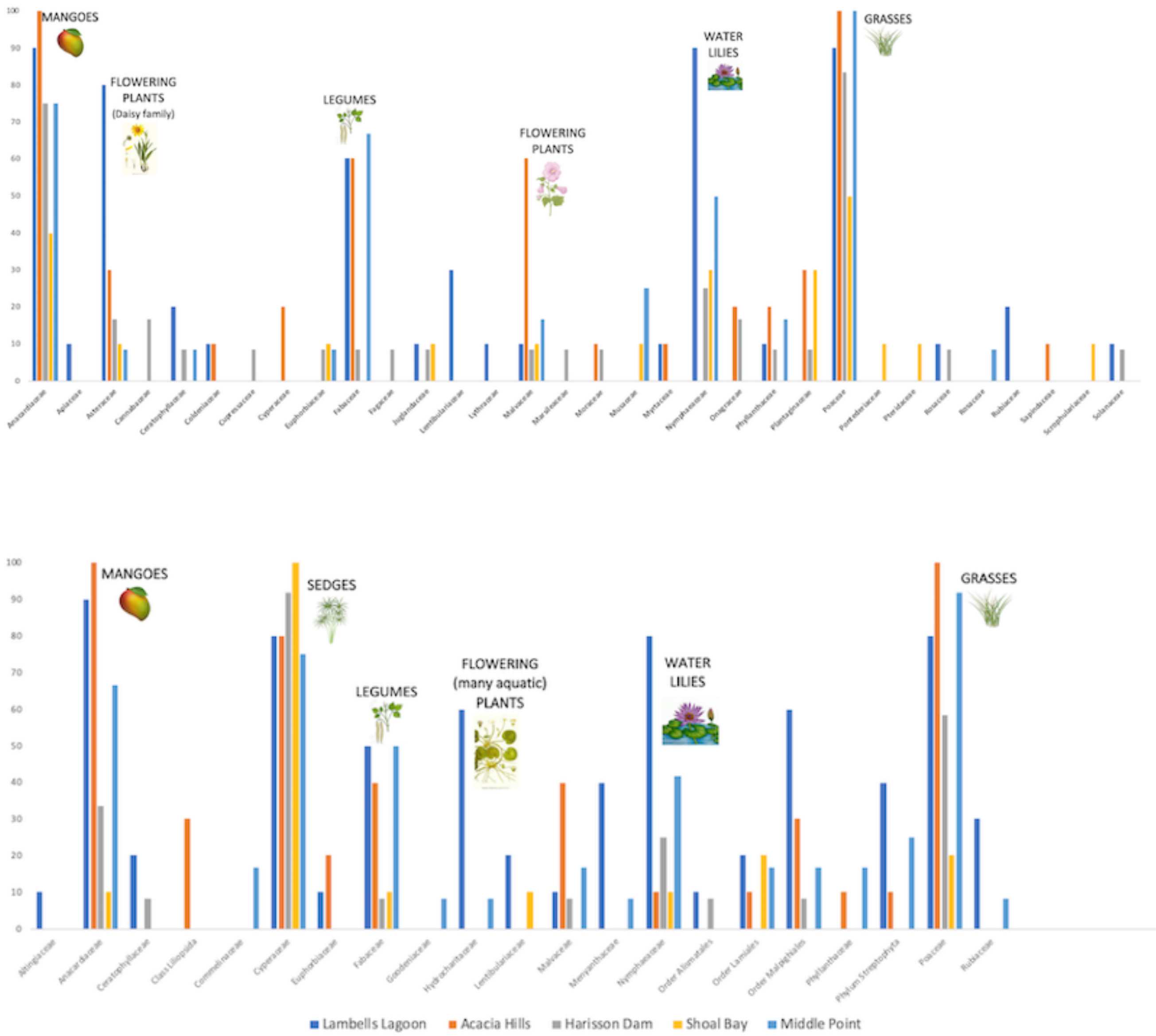


Figure 12. Proportion of samples (%) in which each plant family was detected with 1) rbcL assay (top), and 2) trnL assay (bottom) at each location sampled.

Research Component 2: Evaluation of adverse stimuli deterrents

Assessment of current practice of using a vehicle to move geese from the orchards

A common strategy to deter geese from mango orchards in the NT is to drive vehicles around the orchard and scare geese by using the vehicle itself, with- or without using the horn or some other sound device (e.g., gas gun). We assessed goose density and mango damage between orchards that engaged in this practice and those that did not use any management techniques. The results showed that early in the season when goose levels were low, there was no difference in the density of birds between managed versus unmanaged orchards. As the season progressed both farms showed an increase in the density of Magpie Geese, however, after a few weeks this was reduced in the managed orchard, whilst the numbers remained high in the unmanaged orchard (Figure 13).

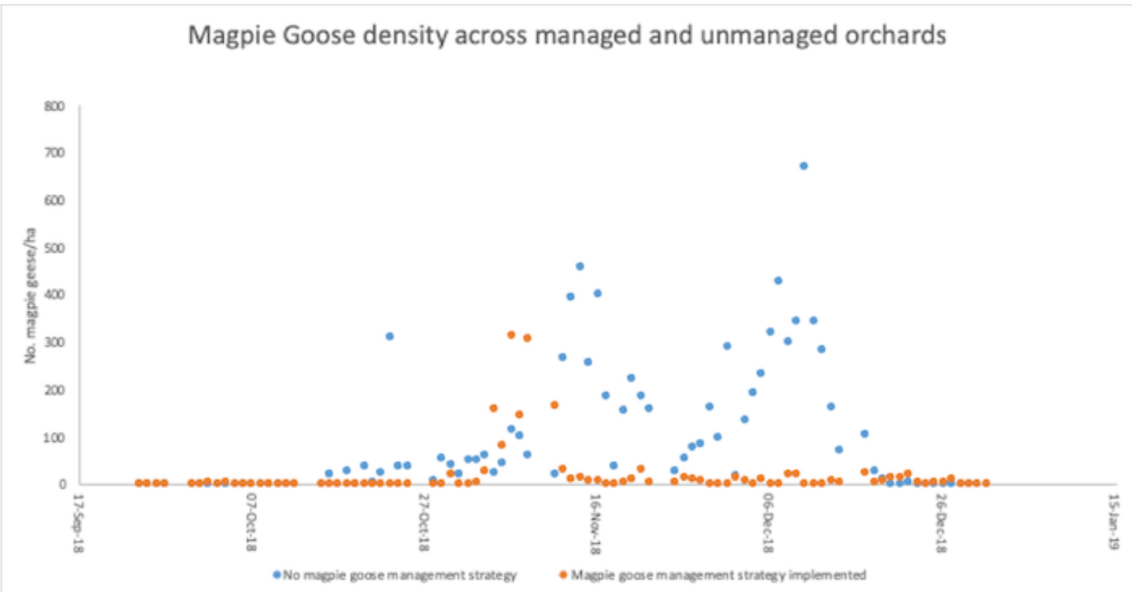


Figure 13. Comparison of daily average goose density between a managed and unmanaged orchard

For all monitored areas, we assessed the proportion of bird damaged fruit both on trees and on the ground around the trees. We found that the proportion of damage was very low in both managed and unmanaged orchards (< 3%). The amount of bird damaged fruit on the trees and on the ground was similar between managed and unmanaged orchards (Figure 14). Whilst scaring did reduce the number of birds on orchard, it did not seem to translate into less bird impact upon the fruit.

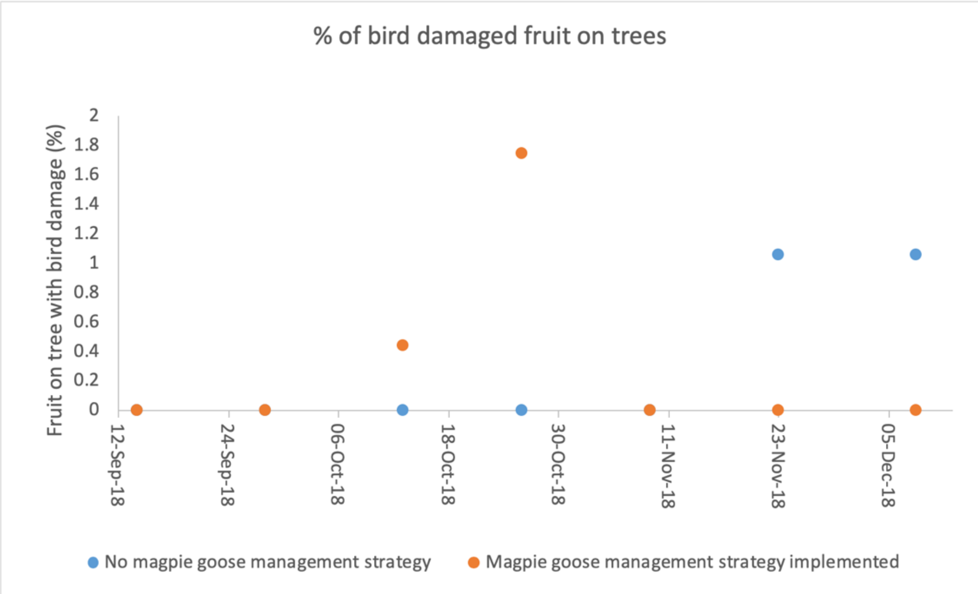


Figure 14. The percentage of bird-damaged fruit on trees between goose managed and unmanaged orchards.

Chemical Deterrents

Trials of four chemical bird-specific deterrents showed virtually no impact upon goose behavior or occurrence (Figure 15a, b). The birds landed in the sprayed areas at the same rate as in the non-sprayed areas, and if left unattended, all sites would attain similar population levels. All fruit piles that were placed on the ground (with or without application of chemical deterrents) were consumed at equal rates by geese. Despite anecdotal reports from previous user farmers and providers of the chemical deterrents, the products assessed did not alter the Magpie Goose fruit-eating behaviour. Although other potential chemical deterrents exist, the four products assessed in this study were pre-approved as safe for food crops and commercially available in Australia.

Figure 15a. Observations by a remote camera 7 hours after application of the chemical D-Ter.

Figure 15b. Observations by a remote camera 18 hours after application of the chemical D-Ter. All mangoes were eaten.

Auditory Deterrents

Long-Range Acoustic Device (LRAD) on quad bike

The use of this device deployed at set locations throughout a large mango orchard proved effective at deterring geese. The geese left immediately but did return within the same day or the next day (Figure 16). However, as the season progressed the number of geese on the orchard gradually decreased. The number of mangoes that had received goose damage remained low even during peak periods of goose presence.

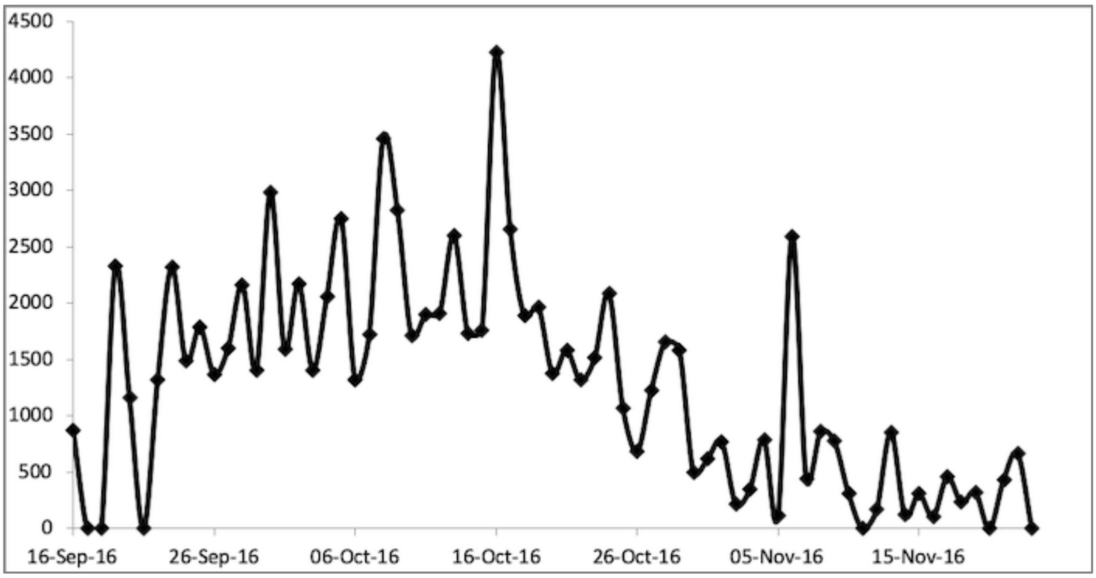


Figure 16. The total number of geese estimated each day on an orchard as counted when they are dispersed after using the LRAD. The y-axis is Magpie Goose abundance.

Acoustic device mounted on a drone

Drone trials using loudspeakers broadcasting Canada Goose (*Branta canadensis*) distress calls proved a very effective method of deterring Magpie Geese from mango orchards. Geese were quickly dislodged from orchard blocks (Figure 17). While some orchards remained goose-free until the following day, we observed returns to similar goose abundance within approximatively 2 hours on other orchards. However, it is unknown if these birds were the same or different individuals that were initially scared off. The main drawbacks of this method are the costs associated with purchasing the equipment, training personnel and operating flights on a regular basis. Some spatial limitations may also occur as the drone must remain within line of site of the operator. Advances in technology will likely allow for the complete automation of flights and recharging capability, opening the potential for a reasonably hands-off deterrent strategy in the future.

Figure 17. The DJI Matrice 600P drone clearing out the Magpie Geese from the orchard.

Outputs

DESCRIPTION	TITLE	DATE	LOCATION
Hort Innovation Online Article	Curbing the effects of Magpie Geese on mango orchards	2-Mar-16	
HIA Project - Extension meeting Workshop	Workshop to manage the growing issue of magpie geese on mango orchards	21-Apr-16	Acacia Hills, NT
ABC Rural - News Article	Researchers and farmers unite to find ways of stopping magpie geese eating mangoes	26-Apr-16	
Mango Matters - Magazine Article	Magpie Goose project takes flight	10-Jul-16	
NT Farmers - Newsletter	Magpie Goose Project 2016	Aug-16	
NT-AMIA Pre-season roadshow - Presentation	Magpie Geese on mango orchards update	25-Aug-16	Humpty Doo, NT
NT News, Sunday Territorian - News Article	When farmers and hunters unite, lots can be achieved, and you can hel our research too	20-Nov-16	
Mango Matters - Magazine Article	Magpie Geese on mango orchards update	19-Jan-17	
11th Australian Mango Conference - Presentation	Magpie Geese on mango orchards: Understanding behaviour to improve management	4-May-17	Bowen, QLD
11th Australian Mango Conference - Presentation	Magpie Geese on mango orchards: Understanding behaviour to improve management	5-May-17	Bowen, QLD
HIA Project - Update to growers - Presentation	Magpie Geese on mango orchards update	25-May-17	Acacia Hills, NT
ABC Rural - News Article	First year of research reveals techniques to deter magpie geese from mango orchards	26-May-17	
CDU Media - Online news article	Research to help solve mango industry issues	19-Jun-17	
NT-AMIA Pre-season roadshow - Presentation	Magpie Geese on mango orchards update & plans for upcoming season	16-Aug-17	Humpty Doo, NT
NT Field & Game pre-season - Presentation	Magpie Goose Research at CDU and how you can help	22-Sep-17	Knuckey Lagoon, NT
NT Farmers - Newsletter	Magpie Geese on mango orchards update	Oct-17	
Mango Matters - Magazine Article	Magpie Geese on mango orchards update	07-Oct-17	
NT Government (DPI) - Mango Research & Development Forum - Presentation	Avoiding a wild goose chase: your opinion matters	9-May-18	Berrimah, NT
NT Government (DPI) - Mango Research & Development Forum - Presentation	Understanding and mitigating the aggregative response of the Magpie Goose to mango orchards in the Northern Territory	9-May-18	Berrimah, NT
NT Government (DPI) - Mango Research & Development Forum - Presentation	Understanding and mitigating the aggregative response of the Magpie Goose to mango orchards in the Northern Territory	10-May-18	Katherine, NT
NT-AMIA Pre-season roadshow - Presentation	Understanding and mitigating the aggregative response of the Magpie Goose to mango orchards in the Northern Territory	Aug-18	Humpty Doo, NT
NT Field & Game Goose Fever Expo - Extension activity	Magpie Goose Research at CDU and how you can help	16-Sep-18	Knuckey Lagoon, NT
Charles Darwin University - Origins - Magazine Article	Finding a fit for farmers and magpie geese	Oct-18	
Mango Matters - Magazine Article	Last field season for the Magpie Geese on mango orchards project	8-Oct-18	
In preparation ***Hand-out for mango growers and managers - Extension material***	Recommendations for deterring Magpie Geese from mango orchards	Jul-19	

DESCRIPTION	TITLE	DATE	LOCATION
In preparation ***Australasian Ornithological Conference - Presentation***	Fine-scale movements and space use of the Magpie Goose in a changing landscape	Jul-19	Darwin, NT
In preparation ***The Australian Wildlife Management Society Conference - Presentation***	Resource use in dynamic landscapes: using individual movements to mitigate human-wildlife conflicts.	Dec-19	Darwin, NT
In preparation ***Peer-reviewed journal publication***	Movements of Magpie Geese in an increasingly developed landscape		
In preparation ***Peer-reviewed journal publication***	Habitat use of Magpie Goose in a mixed natural-agricultural landscape		
In preparation ***Peer-reviewed journal publication***	Using DNA metabarcoding to evaluate the reliance on mangoes during a bottleneck phase in the annual cycle of Magpie Goose		
In preparation ***Doctoral thesis - Amélie Corriveau***	Movements, habitat use, and diet of the Magpie Goose (*Anseranas semipalmata*) in an agricultural landscape of the Northern Territory, Australia.		

All outputs still in preparation will be sent to HIA as published documentation to be included as attachments or appendices to this report.

Monitoring and evaluation

Challenges

Some challenges were encountered when conducting research activities on commercially operated mango orchards. This initially affected trapping of Magpie Geese (e.g., withdrawal from a participating farm) which was resolved on a case-by-case basis with the collaboration of different stakeholders and collaborators Further, the lack of any controlled environment prevented to test the effectiveness of some operations robustly. Additionally, one research component was delayed due to the political situation around changes to Magpie Goose hunting season length and bag limit enforced by the NT Government for the 2017 season. Given the partnership between this project and NT Government, data collection was postponed for a year.

This study was carried out over 3 mango seasons. There was a large variation between these seasons in the timing of mango harvest and arrival of Magpie Geese on orchards. Therefore, management recommendations need to be considered in light of such variation and replicated over multiple years to test their long-term sustainability.

In the original project proposal, stable isotope analysis of goose tissues was suggested to assess diet. However, DNA metabarcoding was used instead for the final project. This novel approach was proved to be a much more appropriate method for assessing dietary items given the accessibility to Magpie Goose fresh carcasses. The relative costs of the analyses were comparable.

The following are the evaluation questions that were originally proposed for this project and how they were monitored.

Project Evaluation	**Monitoring**
Are sound stimuli effective for reducing geese numbers long term when accompanied with lethal measures	We trialed sound devices, with and without shooting. However, it was not possible to do this on the same orchard.
How effective is mobile sound disturbance when not accompanied with lethal measures	We trialed sound devices, with and without shooting. However, it was not possible to do this on the same orchard.
How effective is shooting at reducing goose numbers	The lack of control orchards to compare the impacts of this management strategy prevented robust analysis
What is diet of goose on orchard	This question was answered, and the results are in the outcomes section of this project.
Does goose diet vary on orchard compared with native wetlands	This question was answered, and the results are in the outcomes section of this project.
Do birds remain within local areas or move	This question was answered, and the results

throughout the region	are in the outcomes section of this project.

Project impact

This research was guided by an advisory committee with members from various government authorities concerned with agriculture and wildlife management, as well as mango growers and industry representatives. The diverse backgrounds of the committee served to guide the research team towards a common goal. Therefore, we believe that the findings from this research are directly applicable to the sustainable management of Magpie Geese on mango orchards. The findings will be implemented and actioned through an integrative pest management strategy led by Department of Primary Industry Resources and in collaboration with selected growers and extension personnel from the Australian mango industry.

Recommendations

A major finding of this project was that the geese are migrating to the Darwin agricultural area from all over northern Australia. They are arriving from many different wetlands, suggesting that it is the draw of good habitat within the Darwin agricultural area rather than degradation of the wetlands that has resulted in these late dry season aggregations. The geese observed in the Darwin Region at the end of the dry season do not all nest on the same wetland. Therefore, culling pest mitigation strategies are unlikely to be successful, as they would require depletion of a major component of the Australian population. Within any one mango season the geese are highly mobile moving between orchards and other areas far outside the Darwin agricultural area. Geese present on an orchard one week are unlikely to be the same birds on the orchard a few weeks later. This is why shooting the birds showed not be considered an effective long-term management strategy. Whilst it does immediately reduce the number of birds on the orchard, new birds will arrive constantly throughout the season. If shooting individual geese significantly reduced the number of geese within or between seasons then there would be no geese in hunting reserves.

On a positive note, we do believe it would be possible to reduce the number of Magpie Geese visiting the Darwin mango growing region each year. This is because Magpie Geese move between mango orchards and other areas such as urban gardens, parks, and wetlands throughout the late dry season. They are not fixated to a single orchard or even the Darwin agricultural area. If the mango-orchard was to be made a less favorable environment then we foresee that they would choose not to go there. This will however, require a coordinated effort between growers across the region. Further, this study showed that individual geese moved between a mango orchard, a local roosting site (forested areas), and an open water source (for drinking and bathing) at least once each day. Removal or making one of these areas unfavourable for the geese will result in them moving to another area.

We provide tables below with recommendations at the farm scale (Table 1) and those that would require a more coordinated regional implementation (Table 2). Our recommendations are based upon observations across a large number of orchards over three seasons. Some of these recommendations may not be economically feasible or be more expensive to implement than the loss of the mango crop due to the geese. Therefore, our primary recommendation to all growers is to first quantify the financial loss due to

Magpie Geese before implementing any management strategies.

Table 2. Recommendations for Magpie Goose deterrent implementation at the farm scale.

RECOMMENDATIONs	**RATIONAL**
Estimate the proportion of mangoes being lost to the geese each season.	This is required to facilitate a regional approach and leverage government funds to solving the issue.
Regularly remove fallen mangoes from the ground	The geese primarily feed on mangoes from the ground. Removal of fallen mangoes will reduce patch quality of orchard for foraging geese.
Remove all mangoes from trees post-harvest	Removal of mangoes post-harvest will reduce patch quality of orchard for foraging geese..
Remove grass and weeds around trees	The geese feed on sedges and grasses. Removal of grasses will reduce patch quality of orchard for foraging geese.
Remove available water sources in the orchard	The geese need water regularly. Removal of water sources will reduce patch quality of orchard for foraging geese
Do not dump waste mangoes where geese can access	Dumping of mangoes near orchards will increase patch quality of orchard for foraging geese.
Install a visual barrier fence under trees. This only needs to be taller than a goose	Geese like to be out in the open where they can keep a watch for predators. They are cautious of venturing into enclosed areas.
Develop trellised high-density crops that could be netted or poly tunneled	Protective barriers are used the world over to protect fruits from birds, and this could make it a viable option.
Increase height of lowest mangoes on trees to be higher than a goose	Geese predominately feed on mangoes on the ground or those they can reach on the tree whilst standing on the ground

Table 3. Recommendations for Magpie Goose deterrent for implementation at the regional scale.

RECOMMENDATION	RATIONAL
Estimate the proportion of mangoes being lost to the NT industry due to geese each season.	This is required to facilitate a regional approach and leverage government funds to solving the issue.
Develop an adaptive management approach that is observed and coordinated at the regional scale.	Geese do not behave the same on all farms at all times. Coordination and sharing is the only way to develop a sustainable regional strategy.
Fund the development of an early warning strategy to predict goose numbers and duration of goose interaction with the mango crop	The fruit set is determined by the minimum temperatures earlier in the year, whilst the goose arrival time is dependent on the extent of the previous wet season. Thus, it would be possible to calculate and provide warning to farmers of expected arrival time.
Develop strategy to pool resources across farms to fund aversive sound mitigation strategies (these can either be delivered on a quad or by drone across a number of farms)	A drone carrying the correct sound equipment and recordings can clear an orchard of geese in a few minutes. Drone equipment and operators are expensive and it may only be viable if a number of closely located farms pooled resources to higher a single operator.
Identify local roosting areas and scare birds from roosting areas in the middle of the day or at night.	All birds that travel to the orchards have a close by roost that is usually comprised of bush land with a number of tall trees for them to post look-outs from.
Identify local off farm water sources and net or use other strategy to prevents birds from accessing the water	All birds that travel to the orchards have a close by open water source that they visit one or two times per day.
Do not stop management strategies once the mango harvest is over	Although the harvest is over the geese will still remain on orchard. And amangemnt should continue to enforce that the orchard is not a habitable area for geese.
Costs of magpie goose management strategies and mangoes lost due to magpie geese need to be more integrated into farm business plan, particularly for new farms as industry grows	Geese are going to have a significant impact upon mango farms for a number of years. Our estimates are that crop loss is low but significant.

Refereed scientific publications

Journal articles in preparation

Corriveau, A., Klaassen, M., Loewensteiner, D., Garnett, S.T., Christian, K.A., Campbell, H.A. In prep. Movements of Magpie Geese in an increasingly developed landscape.

Corriveau, A., Klaassen, M., Loewensteiner, D., Garnett, S.T., Christian, K.A., Campbell, H.A. In prep. Habitat use of Magpie Goose in a mixed natural-agricultural landscape.

Corriveau, A., Coghlan, M., Klaassen, M., Garnett, S.T., Christian, K.A., Campbell, H.A. In prep. Using DNA metabarcoding to evaluate the reliance on mangoes during a bottleneck phase in the annual cycle of Magpie Goose.

References

Australia Mango Industry Association. 2019. https://www.industry.mangoes.net.au/. Accessed 16/04/2019.

Bracis C., Bildstein K., Mueller T. 2018. Revisitation analysis uncovers spatio-temporal patterns in animal movement data. Ecography. doi: 10.1111/ecog.03618 (URL: http://doi.org/10.1111/ecog.03618).

Delaney, R., F. Y., and K. Saalfeld. 2009. Management program for the Magpie Goose (*Anseranas semipalmata*) in the Northern Territory of Australia, 2009–2014. Parks and Wildlife Service of the Northern Territory, Department of Natural Resources, Environment, the Arts and Sport, Darwin.

Exsystex. 2019. http://www.ensystex.com.au/birdaway.html. Accessed 16/05/2019.

Frith, H. J., Davies, S. J. J. F. 1961. Ecology of the Magpie Goose, Anseranas semipalmata latham (Anatidae). Wildlife Research 6:91-141.

Hunt, W. 2016. Magpie geese damage to mango crops. https://dpir.nt.gov.au/primary-industry/primary-industry-publications/newsletters/regional-newsletters/tp/top-paddock-june-2016/magpie-geese-damage-to-mango-crops. Department of Primary Industries and Resources, Darwin, NT. Accessed 20/02/2017.

Lorac. 2019. https://www.easypestsupplies.com.au/images/D%20Ter%20MSDS%20Feb%202015.pdf. Accessed 16/05/2019.

LRAD Corporation. 2019. https://www.lradx.com/application/wildlife-control-preservation/agriculture-fisheries/ . Accessed 18/04/2019.

Multicrop. 2019. http://www.multicrop.com.au/pdfs/Scat-information-sheet.pdf. Accessed 16/05/2019.

Poinar H.N., Hofreiter, M., Spaulding, W.G., Martin, P.S., Stankiewicz B.A., Bland, H., et al. 1998. Molecular coproscopy: dung and diet of the extinct ground sloth Nothrotheriops shastensis. Science 281(5375). 402-406

Resource Bio Management. 2019. https://www.resbioman.com.au/. Accessed 16/05/2019.

Roshier, D. 2008. Waterfowl movements in agricultural and natural wetland landscapes. Rural Industries Research and Development Corporation, Kingston, ACT.

Taberlet, P., Coissac, E., Pompanon, F., Gielly, L., Miquel, C., Valentini, A., Vermat, T., Corthier, G., Brochmann, C., Willerslev, E. (2007) Power and limitations of the chloroplast trnL (UAA) intron for plant DNA barcoding. Nucleic Acids Research. 3(3). E14. https://doi.org/10.1093/nar/gkl938

Tracey, J., M. Bomford, Q. Hart, G. Saunders, and R. Sinclair. 2007. Managing bird damage to fruit and other horticultural crops. Bureau of Rural Sciences, Canberra.

Whitehead, P. 1991. Magpie Geese, mangoes & sustainable development. Australian Natural History

23:785-792.

Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

Acknowledgements

The research team would like to acknowledge all mango farmers from different growing regions of the Northern Territory, Western Australia and Queensland who helped in various ways throughout the project – from offering access to their orchards, assisting on the ground and providing valuable insight and observations. This project would not have been possible without the guidance and support of all former and present members of the project advisory committee: Tim Clancy (DENR), Tracey Duldig (NTPWC), Trevor Dunmall (AMIA), Samantah Frolov (AMIA), Sally Heaton (NTPWC), Warren Hunt (DPIR), Brenda Kranz (Hort Innovation), Martina Matzner (Acacia Hills Farm; AHF), Ross Maxell (Jabiru Tropical Orchards), Greg Owens (NTFA), Camilla Phillips (NTFA), Keith Saalfeld (DENR), Han Shiong Siah (Tropical Primary Products), Joe and Clare Visini (Cheeky Farms).

We also thank Northern Territory private landowners, commercial growers, and farm managers who allowed access to their properties for different components of this project: Barry Albrect (Arnhem Mangoes), Karl Jurkijevic, Martina Matzner (Acacia Hills Farm), Ross Maxell (Jabiru Tropical Orchards), Kathie Musumeci (Cheeky Farms), Wayne and Robert Quach, Barry Lemcke, Han Shiong Siah (Tropical Primary Products), Tou Saramat Ruchkaew and Ian Quin (Tou's Garden), Leo Skliros (Skliros Produce), Joan and Bill Stewart (Milkwood Tropical Orchards).

We thank Northern Territory local associations and recreational hunters for their collaboration in facilitating Magpie Goose carcasses collection for the diet analyses: Dario Bartelotti, NT Field & Game, Glenn Giffin, Bart Irwin, Amy Kirke, Brett Ottley, Peter Phillips, Damien Stanioch, Jason Stephens, Rohan and Jess Walker. We thank Dr. Cathy Shilton and her team from NT Berrimah Veterinary Laboratories (DPIR) for granting access to facilities and supporting laboratory dissections of Magpie Geese, and Michael Bunce's team at TREND Laboratory at Curtin University, Perth, WA, who provided essential expertise and support for molecular analyses.

Finally, the completion of this project would not have been possible without the commitment, dedication, and availability of a large number of academic, technical and support staff, volunteers and students from Charles Darwin University and other institutions – to only name a few; Nicholas Anderson,

Aurélie Baisnée, Stuart Baker, Dr. Mila Bristow, Dr. Mariana Campbell, Sheila Carrick, Carl Hermiston, Darren Hill, Brad Kenny, Shannon Leeson, David Loewensteiner, Matt Northwood, Brett Ottley, John Rawsthorne, Paige Richter, Rebecca (Lerhke) Rogers, Corinne Schlierenzauer, Damien Stanioch and Marko Taalkis.