Cost-Benefit Analysis of the Yellow Crazy Ant Eradication Program

Report Prepared for the Wet Tropics Management Authority

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Acknowledgement

The Wet Tropics Management Authority was contracted $7.5 million by the Australian Government to carry out a National Landcare Program (NLP) – Emerging Priorities program to deliver “**Control of yellow crazy ant infestations in and adjacent to the Wet Tropics World Heritage Area**.”

Concurrent to the NLP funding, the Queensland Department of Environment and Heritage Protection also provided $3 million to help manage yellow crazy ants in the Wet Tropics World heritage Area.

These combined funds have provided funding for three years of the Authorities proposed ten year yellow crazy ant eradication program.

The Authority was required to deliver a cost benefit analysis as part of the NLP Funding Agreement.

Australian Government | National Landcare Program

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Background

The Wet Tropics Management Authority (WTMA) is attempting to eradicate yellow crazy ants in and next to the Wet Tropics World Heritage Area (WTWHA). Eradication efforts have been funded by two overlapping projects. The first project ($2 million) was funded by the Australian Government's Caring for Our Country Target Area Grant (TAG) program (TAGEOI14P2-00261) for the period 2013-2018. The second project ($10.5 million) was funded by the Australian Government's National Landcare Program (NLP) ($7.5 million) and the Queensland Government ($3 million) for the period 2016-2019.

Further funding is required to achieve eradication of yellow crazy ants (YCA). WTMA requested the University of Melbourne to estimate the costs and benefits of continuing the Yellow Crazy Ant Eradication Program (YCAEP).

This cost benefit analyses has determined that that benefits of eradication are likely to substantially exceed costs. Over a 30-year time horizon the program's net present value (NPV), and benefit-cost ratio (BCR) are $6.1B, and 178:1, respectively, at a 7% discount rate. These values increase to $9.7B, and 254:1, respectively at a 3% discount rate. These figures are conservative, and benefits are likely to be substantially larger if additional factors were to be considered in the modelling.

The benefits of continuing the program are the environmental and socioeconomic costs that would be avoided by eradicating YCA. To estimate these costs, a "without YCAEP" scenario was defined in which eradication efforts cease and control efforts are focused on asset protection. The assets considered in the "without YCAEP" scenario are residential dwellings and agricultural land and it is assumed that these assets would be protected by households, and agricultural producers, respectively.

An additional, and critically important, asset is the WTWHA. Protection of the WTWHA's irreplaceable biodiversity and ecosystem services is the primary rationale for the YCAEP. If the Program ends, efforts to protect the WTWHA may have a substantial cost. This cost is estimated here but is reported separately from the baseline analysis. In addition, an assessment is made of the cost-effectiveness of eradication efforts relative to containment. The focus of the latter analysis is not on precise estimation of WTWHA protection costs but rather, on comparing relative magnitudes of protection and eradication costs, and in particular, on whether eradication is likely to be substantially more cost-effective than containment.

In the "without YCAEP" scenarios considered, control efforts are aimed at reducing losses ("damages") to households, producers and the environment. Damages include nuisance and health impacts on households, yield losses in agriculture, and species and ecosystem service losses in natural areas. Control efforts may reduce, but not eliminate, damages. For example, households may experience losses from the risk of contact with YCA outside their homes despite applying pesticides within their homes. Imperfect control methods that fail to remove all YCA individuals and therefore result in residual damages may also be applied in agricultural and natural areas. For example, as noted above, there is substantial uncertainty about the extent to which control efforts will slow spread and reduce ecological impacts of YCA in the WTWHA. There also is uncertainty, based on discussions conducted for this analysis with WTMA staff and sugar cane producers, about the extent to which producers can reduce YCA-induced yield losses. Damages that are not captured in markets, such as species losses and residents' wellbeing and amenity losses, can be challenging to estimate. This not only reflects uncertainty about the biophysical factors underpinning those damages (such as the number of species facing extinction because of YCA), but also uncertainty about the values people place on avoiding those biophysical outcomes. Values placed on species losses, as estimated in this analysis, are based on the results of a previous household survey (Akter *et al*. 2015).

The following control costs and damages are considered in the "without YCAEP" scenario:

- Household pesticide costs in the project region.
- Wellbeing losses to households and tourists in the project region from the risk of contact with YCA.
- Wellbeing losses to households in Australia arising from the adverse impacts of YCA on native biodiversity.
- Pesticide costs for selected agricultural industries in the project region (e.g. sugar cane, tree fruits, plantation fruits and beverage and spice crops).
- Yield losses for selected agricultural industries in the project region (sugar cane).

Control costs to protect the values of the WTWHA are considered separately from the baseline analysis, based on the same simulations conducted for the baseline analysis. The simulations are conducted for 30-year periods, with 50 iterations.

Main findings

The benefits of eradication are likely to substantially exceed costs:

- Over a 30-year time horizon, if environmental benefits are included, under plausible assumptions on the number of species conserved, the program's net present value (NPV), and benefit-cost ratio (BCR) are $6.1B, and 178:1, respectively, at a 7% discount rate.

- These values increase to $9.8B, and 254:1, respectively at a 3% discount rate.

The YCAEP has a large estimated NPV and BCR even if environmental benefits are excluded.

- For a 30-year time horizon, these program values are $513M, and 16:1, respectively, at a 7% discount rate, and $823M, and 22:1, respectively, when the discount rate is reduced to 3%.

Most of the non-environmental benefits of eradication are to domestic tourists, with smaller but significant benefits to regional residents.

- The tourism industry could also incur substantial losses if the presence of YCA causes a reduction in visitor numbers. This partly depends on the extent to which YCA infestations in tourism locations are controlled by tourism industry operators and government agencies. It also depends on the sensitivity of tourism numbers to the risk of contact with insects (that spray formic acid). Neither of these factors are known at present.

- In the absence of this information, the primary focus of this analysis is on the losses to Australian tourists who continue to visit the region rather than on the North Queensland tourism industry.

Benefits to agricultural industries are estimated to be much smaller than benefits to residents, domestic tourists and people concerned about the environment. This reflects several factors, including:

- The large number of residents in the project region and domestic visitors to the region.

- The potentially devastating ecological impact of YCA.

- The scope for agricultural producers to reduce yield losses by applying pesticides known to be effective at controlling YCA, subject to these pesticides being registered for use in controlling yellow crazy ants.

A failure to eradicate YCA is likely to impose large ongoing costs on the government to protect the WTWHA. Discussions with a leading international YCA expert consulted for this review (Dr Ben Hoffman, CSIRO) indicated that even with substantial protection efforts, large adverse ecological impacts would be unavoidable over the long term.

- If protection efforts will reduce YCA abundance at selected locations without significantly reducing YCA spread rates within the WTWHA, the annual expected cost of YCA treatment within the WHA is likely to increase to almost $300,000 per year within 20 years and more than $400,000 per year within 30 years, at a total present value cost of over $6M over a 30 year horizon. This cost could increase substantially if a longer time horizon were considered because of the rapid rate of spread of YCA within the WHA.

- Much larger costs would be incurred if WHA protection efforts will include active monitoring rather than relying solely on community monitoring. Active monitoring is likely to be needed because large areas within the WHA are either not inhabited by people and are rarely visited, or are inhabited at low population densities, reducing the effectiveness of community monitoring.

- Eradication of YCA is likely to be more cost-effective than containment as a strategy for protecting the WTWHA.

- Unless all YCA infestations are removed, a substantial area within and near the WTWHA will be at risk of infestation within the next 20 years. This reflects the close proximity of existing infestations to the WHA and the risk of human assisted movements into the WHA from other infestations. Even with a low natural budding rate YCA has the potential to invade WTWHA. An additional issue to note is if the WHA is infested with YCA it is unlikely to be detected because much of the area has limited access and low to no human population. The area would also be difficult to treat because of limited access points, rugged and hilly terrain, and canopy that will prevent bait distribution to the ground even when bait is dropped by helicopter.

- The high likelihood that the WTWHA will become occupied by YCA even when most current infestations are removed implies that large areas of active surveillance would be needed to detect new incursions in the WHA early enough to slow spread and minimise damages there. The long-term cost of actively monitoring large areas and applying treatment to remove new infestations when they are detected is likely to exceed the cost of eradicating all known current infestations.

Background

Yellow crazy ants (*Anoplolepis gracilipes*) (YCA) are one of the world's 100 worst invasive species (Lowe *et al*. 2000). Previous assessments of YCA invasions have demonstrated that YCA can dramatically reduce native species richness in invaded areas, including in the Seychelles (Bos *et al*. 2008), Christmas Island (O'Dowd *et al*. 2003), and Hawaii (Plentovich *et al*. 2011). Native species losses include direct losses of competing invertebrate species and indirect losses resulting from ecological interdependencies, which can result in "ecological meltdown" in extreme cases such as Christmas Island (O'Dowd *et al*. 2003). YCA can also cause large losses to people living in infested areas through nuisance and health effects (Lach and Hoskin 2015) and can also adversely affect agricultural producers (Young *et al*. 2001) through reducing yields and/or increasing pesticide costs.

YCA was first detected in Cairns and its southern suburbs in 2001, and an eradication program was initiated by the Department of Natural Resources and Mines (DNRM) and Biosecurity Queensland as part of a larger state-wide program. Later discoveries of YCA across the state, including in and around the WTWHA led to the state-wide eradication program being discontinued. An application was then made by WTMA to continue eradication efforts in and around the WTWHA. The program has been funded by the Australian Government and the Queensland Government in two overlapping projects, as described in the Executive Summary.

Spread model

To estimate the economic benefits of eradication, a model was developed to estimate the spread of YCA if eradication efforts cease. The model is an extension of the Australian Animal Disease Spread model (AADIS) (Bradhurst et al., 2015). AADIS is a spatially-explicit stochastic agent-based model that simulates the abundance and spread of pests and diseases in the context of an environment. In this analysis, the modelling unit of interest (or agent), is a 10-ha (approx.) square cell with a side length of approximately 316m. The environment is a 166km x 113km grid bounded by Mossman in the north, Dimbulah in the west, and Tully in the south (Figure 1) with 175,441 cells. The current (December 2018) YCA invasion occupies 154 of those cells (Figure 1).

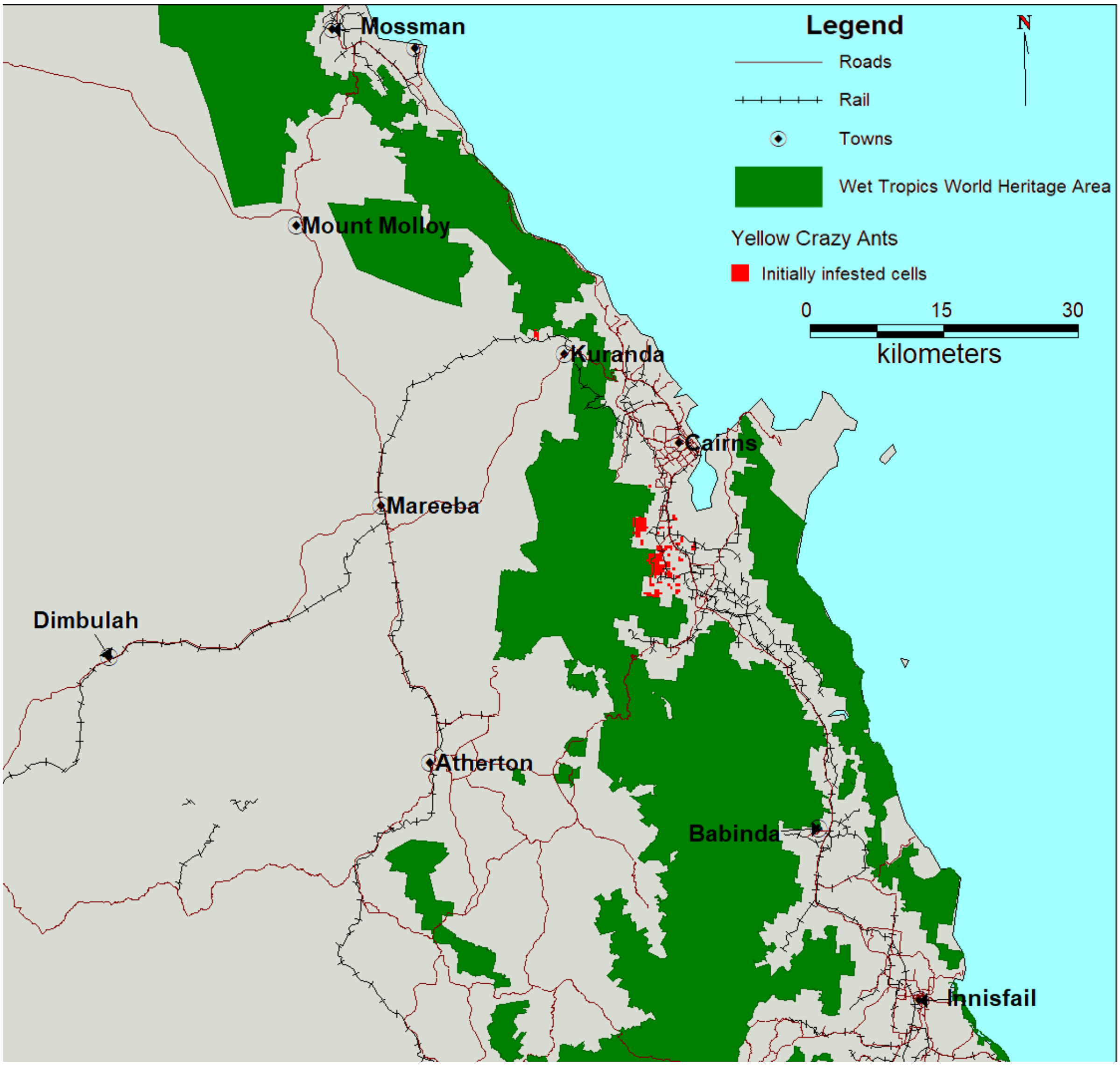

Figure 1: Initial yellow crazy ant population

Each cell has user-defined attributes that may influence YCA spread, including land use and human population density. The relevance of human population density reflects that people can transport YCA, as indicated by the presence of disjunct infestations of YCA in the modelled region (Figure 2).

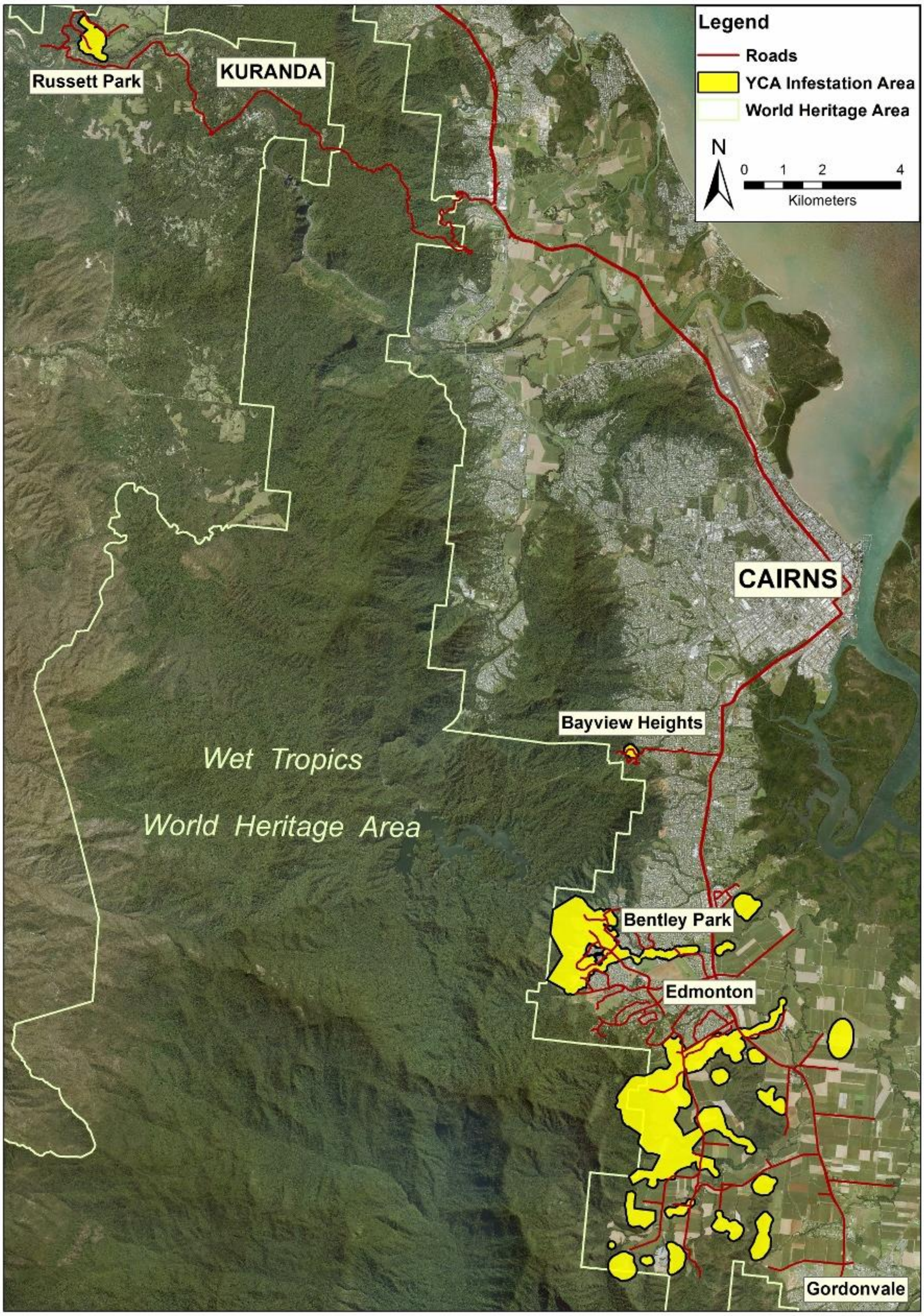

Figure 2: Areas of YCA infestation in 2017

There are known examples where people have transported YCA to distant locations, including a 30km movement of YCA in landscaping materials transported from near Cairns to a residential dwelling on the edge of the WTWHA in Russett Park. This demonstrated the substantial risk that YCA will spread into the WHA due to human assisted movements. In the absence of jump events, YCA spreads relatively slowly and would not reach the WHA for an extended period if current infestations there are removed (assuming that no unknown infestations currently exist near the WHA). The spread model explicitly considers long distance spread and allows for human-assisted spread risks to be larger in locations where more people live or work, and in locations with a larger abundance of YCA.

In addition to considering spatial spread, the YCA spread model explicitly considers the growth of YCA abundance over time. In this analysis, the growth over time of YCA abundance within a cell is estimated with a logistic growth function, with parameters determined in consultation with an international expert in YCA biology and management (Dr Ben Hoffman, CSIRO) and reviewed by a scientific advisor to the Program (Dr. L. Lach, James Cook University). Key assumptions underpinning the modelling of abundance over time are set out in the supplementary material, which is set out at the end of the report.

The spread of YCA between cells is modelled through four concurrent stochastic spread pathways:

1. the steady diffusive spread of YCA over time to adjoining cells. This is mainly due to natural budding, however, in some cells the process is accelerated, for example, in cells that contain cane farms the spread is augmented by short-range hitchhiking jumps from localised cane farming activities.
2. the sporadic spread of YCA over time to non-adjoining cells due to medium-range hitchhiking related to cane farming activities. Spread between cane farms is defined separately than spread from cane farms to cane railway corridors.
3. the sporadic spread of YCA over time to other cells due to human-mediated hitchhiking that is unrelated to cane farming.
4. the sporadic spread of YCA over time to other cells due to water assisted movements (YCA have been observed to form rafts and float downstream, with the potential for viable clusters of ants to spread further distances than natural budding.)

Parameters for each mode of spatial spread were reviewed by a scientific advisor to the Program (Dr. L. Lach, James Cook University) and are reported in the model attachment. A summary of the main parameters used in the spread model is provided in Table 1.

Table 1: Spread model parameters used in estimating benefits from the YCAEP

Spread pathway	Source cell type	Destination cell type	Baseline probability	Dependent on human population density	Distance	Initial population in a newly infested cell
Diffusion	cane railway managed natural	any any any any	0.000466 0.000076 0.000076 0.000028	no	Adjoining cells only	25
Cane farm jumps	cane cane	cane railway	0.000289 0.000289	no	BetaPERT (0.5, 2, 20) km	25
Hitchhiking (human-mediated) jumps	railway, managed, natural	railway, managed, natural	0.000977 (dampened by source cell human population density)	yes	BetaPERT (0.5, 10, 75) km	25
Raftin g jumps	water	water	0.000141	no	BetaPERT (0.5, 0.5, 5) km	25

As the YCA spread model is stochastic, multiple iterations must be run (currently 50 iterations) for any given incursion scenario to capture the range of potential outcomes.

Cost benefit analysis

Cost benefit analysis (CBA) involves the following steps (OBPR 2016):

Table 2: Steps in preparing a cost–benefit analysis (Source: OBPR 2016)

Step	Action
1	Specify the set of options.
2	Decide whose costs and benefits count.
3	Identify the impacts and select measurement indicators.
4	Estimate project impacts.
5	Monetise project impacts.
6	Discount future costs and benefits to obtain present values.
7	Compute the net present value of each option.
8	Perform sensitivity analysis.
9	Reach a conclusion.

The three management options considered in this analysis using the YCA spread model are to: (1) do nothing ("the walkaway scenario" or "baseline scenario"); (2) apply limited control actions within the WTWHA to reduce YCA abundance without substantially reducing rates of spatial expansion within the WHA; and (3) eradicate the invasion. The eradication scenario assumes that virtually all the losses estimated to occur in the "without YCAEP" scenario would be avoided. A comparison of these options informs the decision whether to attempt to eradicate or contain the invasion, or whether to cease most or all management efforts.

To be eligible to receive funding from the Australian Government, a proposed eradication program must provide benefits larger than costs, as specified in Schedule 4, Clause 3 of the National Environmental Biosecurity Response Agreement (NEBRA) (COAG 2012). The program must also have a realistic chance of succeeding (Council of Australian Governments (COAG), 2012). Eradication programs can fail for different reasons, and in some circumstances, failure risk can be reduced by increasing project funding to allow for larger areas to be managed (Spring and Kompas 2015). The risk of eradication project failure can be addressed in CBA in different ways, including by increasing the discount rate to include a risk component. In this analysis, two discount rates are considered that can be interpreted as incorporating two different degrees of risk adjustment. This interpretation reflects that the discount rate often includes two main components: a cost of government borrowing and a risk component. The recommended discount rate for Australian Government projects, including biosecurity projects, is 7%, which is substantially larger than the cost of government borrowing, implying that it incorporates a substantial risk component. Discount rates for projects covering environmental assets are typically much smaller.

Whilst most of the steps listed in Table 2 are included in the NEBRA guidelines on CBA, there are omissions and inconsistencies in those guidelines (Summerson *et al*. 2018). For this reason, we apply the steps listed in Table 2. The main steps are described in more detail below.

Identify YCAEP impacts

The impact of the YCAEP on people, the environment and industries, depends on what would have happened without the YCAEP (the "baseline scenario"). In the baseline scenario defined for this analysis, YCA control efforts would be undertaken by households, industries and government agencies to protect assets rather than to slow the geographic spread of YCA. There is assumed to be no regional containment efforts, and the asset protection actions undertaken are assumed not to influence the rate of geographic spread. Spread estimates in the baseline scenario are made with the YCA spread model.

The eradication project scenario considered here is assumed to be successful eradication of YCA at the planned budget, as estimated by WTMA. The discounted value of this budget is the cost of eradication.

The benefit of eradication is the sum of the costs avoided by implementing the YCAEP, under the assumption that the program will be successful in eradicating YCA. The three types of avoided cost considered in this analysis are: (1) the cost of control activities that would be undertaken by households and industries in infested areas ("control costs"); (2) residual losses incurred by households and industries after control actions are undertaken ("damages") and (3) the cost of control activities within the WTWHA to protect ecological assets there. The different forms of control costs and damages that would be avoided if the YCAEP is successful are listed in Table 2, together with the different forms of cost involved in implementing the YCAEP.

Estimate biophysical impacts of YCAEP and monetary values of impacts

WTMA estimates that eradication will require annual expenditure of $6M over the next seven years. This has an undiscounted total cost of $42M. This is the project cost considered in this analysis.

The benefit of eradication is the monetary value of the household and industry control costs and damages that would be avoided by eradicating the invasion. The cost that would be incurred by government in protecting WTWHA assets is another avoided cost if the YCAEP continues to operate. Although an approximate estimate is made of the treatment costs to protect the WTWHA it is not included in the CBA analysis metrics and not reported here.

These avoided costs are valued with market prices where possible. Table 3 lists the costs and benefits involved in the YCAEP. Valuation methods used to monetise benefits are included in the table.

Table 3: Costs and benefits of the YCAEP

<table>
<tr><th>Costs</th><th>Benefits
(avoided costs compared to “no YCAEP”)</th></tr>
<tr><td>
<u>Fixed costs</u> (costs that do not increase substantially with invasion size):

Community engagement (regional).
Scientific research.
Administration.
Planning.
Regulatory costs (if applicable).

<u>Variable costs</u> (costs that increase substantially with invasion size):

Monitoring

Regional monitoring to delimit invasion as a whole (includes traceback activities);
Pre-treatment delimitation monitoring; and
Post-treatment monitoring to confirm absence.

Treatment.

</td><td>
<u>Control costs</u> (costs of activities to mitigate YCA threats):

Pesticide expenditures by households and industries (market prices).
Changed commercial activities by industries, such as washing sugar cane harvesting machinery or restricting movements of vehicles (market prices).
Treatment costs incurred by government in protecting the WTWHA.

<u>Damages</u> (losses other than control costs):

Losses of wellbeing to people living in or visiting areas affected by YCA (non-market valuation survey).
Losses of wellbeing to people from loss or degradation of environmental assets (non-market valuation survey).
Crop losses to agricultural industries (market prices).

</td></tr>
</table>

Avoided costs that can be valued with market prices include pesticide expenditures and yield losses in agricultural industries. Avoided costs that cannot readily be valued with market prices include impacts on householders’ wellbeing from the risk of contact with YCA, and from the loss or degradation of environmental assets. Per-household values of these forms of damage estimated in a previous study (Akter *et al*. 2015) are used to value householder damages in this analysis.

Costs incurred by industries to assist eradication efforts, such as movement controls and improved record keeping to facilitate traceback of incursions, are not considered in this analysis. This reflects that such costs are likely to be small relative to the costs to resource the YCAEP, based on interviews with a small number of industry participants conducted by WTMA for this analysis.

Some of the eradication benefits considered in this analysis are estimated with the YCA spread model (attached). For those benefits, the valuation approach taken was to apply the model to make spatially explicit estimates of YCA occupancy over time. For each grid cell within the estimated annual occupancy map, the cell's YCA infestation likelihood was estimated for each year. This was computed as the proportion of 50 simulation runs in which the cell was occupied in that year. These annual infestation likelihood maps were aligned with digitised maps of residential and agricultural land uses to estimate expected values of impacts.

Valuing benefits to households in the project region

The two main forms of benefit of YCA eradication to households in the project region are avoided expenditures on pesticides in the home and avoided losses of wellbeing from the risk of contact with YCA outside the home. In the cost-benefit analysis of the eradication program conducted by Biosecurity Queensland (2012), it was implicitly assumed that households would suffer no residual losses from contact with YCA after applying pesticides in the home. However, an area that is infested by YCA will potentially have large numbers of YCA in close proximity to homes and in public recreation areas. YCA may also be present in and near work locations. For these reasons, the approach taken in this analysis is to include both pesticide costs and residual wellbeing losses from the risk of contact with YCA during normal activities. As already mentioned, it is likely that some, and perhaps many, households will be concerned at the need to continuously apply pesticides around the home to exclude YCA. For those households, YCA eradication offers an additional benefit from reducing household pesticide exposure. This benefit was not considered in this analysis because of a lack of empirical evidence on the willingness of households to pay for this benefit. A highly approximate indication of the value to households of reducing their pesticide exposure was provided by Garming and Waibel (2009), who found that farmers in Nicaragua were willing to pay (WTP) approximately 28% more for safer pesticides. If households in Australia were willing to pay a similar premium to avoid the need to apply pesticides to control YCA in their homes, this would potentially be worth at least $60/household/annum, assuming annual pesticide expenditures are similar to those estimated in a cost-benefit analysis of the previous eradication program, which was managed by Biosecurity Queensland (Biosecurity Queensland, 2012).

Pesticide costs and the loss of wellbeing from the risk of contact with YCA have been estimated in previous studies (Table 4).

Table 4: Parameters used in estimating household benefits from the YCAEP

Parameter	**Value**
Regional household benefits	
Pesticide costs for home control of YCA[1]	220
Risk of contact with YCA ($/household)	
Mean household WTP* to reduce risk of YCA contact from high to medium[2]	$206.14
Mean household WTP to reduce risk of YCA contact from medium to low[2]	96.44
Mean household WTP to reduce risk of YCA contact from high to low[3]	302.58
National household benefits from avoiding 7 native species extinctions ($ per household)	
Household segment 1	47
Household segment 2	8
Current number of households segment 1[4]	7.476M
Current number of households segment 2[4]	2.109M
Average annual increase in the number of households in each segment over the analysis period[5]	
Household segment 1	134,160
Household segment 2	37,840
Industry control costs[6]	300

1. Source: Biosecurity Queensland (2012).
2. Based on weighted average WTP of households in the two-segment identified by Akter *et al*. (2015).
3. The sum of WTP to reduce YCA contact risk from high to medium and medium to low, which reflects that WTP for the two levels of risk reduction are additive.
4. Based on probabilities of households being in segment 1, and segment 2, of 0.78, and 0.22, respectively (Akter *et al*. 2015).
5. Based on an estimate of the future national average annual increase in household numbers of 172,000 (AIFS undated) multiplied by the probabilities of households being in each of the two segments.
6. The cost of Antoff to cane growers is not precisely known because it is not commercially available, however, is estimated here at $300/ha/year based on 3 treatments at a 5kg/ha application rate (Gareth Humphries, Operations Manager Yellow Crazy Ant Eradication, WTMA, personal communication).

The parameters listed in Table 1 and Table 4 are applied in the present analysis. The general approach taken was to simulate YCA spread in the “without YCAEP” scenario to estimate where and when households will be affected by YCA after the YCAEP is discontinued, and to use the per-household cost parameters in Table 4 to monetise those household impacts. In the first stage of analysis, annual YCA risk maps were estimated with the spread model and combined with spatially explicit estimates of residential dwelling numbers extracted from the most recent (2016) Australian Census of Population and Housing. Residential dwelling numbers were used as a proxy for household numbers. The Census data include estimates of residential dwelling numbers within specific administrative boundaries ("mesh blocks"). Mesh block dwelling numbers were allocated to the grid cells used in our YCA spread model based on the extent of geographic overlap of the mesh blocks and grid cells, using the method of Dodd *et al*. (2017).

For any grid cell occupied by YCA in a specific year, the residual loss to households living in that cell after pesticide application in the home depends on the estimated probability of YCA occupancy there, which determines the risk class in that cell. Residual losses to householders from the risk of contact with YCA were estimated based on a previous Choice modelling study (Akter *et al*. 2015). The survey elicited Australian householders' willingness to pay (WTP) to reduce the chances of invasive ants (specifically including YCA) and other biting insects becoming established in their backyards and outdoor recreation areas. Two levels of risk reduction were considered, from high (50–70%) to medium, and from medium (30–50%) to low (10–30%). Likelihoods of contact with YCA were estimated with the spread model and grouped into three classes similar to those considered in the Akter *et al*. (2015) survey: 0-0.30 (low), 0.30-0.50 (med) and 0.50-1 (high). Two household segments were identified by Akter *et al*. (2015) that differed according to their WTP to reduce the risk of contact with biting insects. The estimated probability of a randomly selected household being in the "high WTP" segment, and "low WTP segment", was 0.78 and 0.22, respectively. These probabilities were used in this analysis to compute a weighted average WTP of a household in the project region to reduce YCA risk by eradicating YCA (Table 4).

Households in locations with a low estimated risk of YCA occupancy are assumed to derive no benefit from YCA eradication until those locations reach the medium or high-risk category, as estimated with the YCA spread model. This approach does not consider the possibility that people living in an non-infested region will visit or work in regions that are in the high-risk category. This implies that the estimated household benefits of eradication made here should be viewed as conservative. However, we include household expenditures on pesticides in the home to minimise the risk of YCA contact there. This reduces the overall risk of YCA contact for people living in affected areas. The benefit of YCA eradication to a household in this analysis depends on the level of YCA occupancy probability in the immediate vicinity of the household. In particular, the benefit to a household living in a high YCA-risk area is the household's WTP to reduce contact from YCA from high to low (calculated as the sum of reducing risk from high to medium, and from medium to low). The benefit to a household living in a medium YCA-risk area is the household's WTP to reduce contact from YCA from medium to low.

Pesticide costs to households were estimated based on a previous cost-benefit analysis of the Biosecurity Queensland-managed eradication program (Biosecurity Queensland 2012). Avoiding these costs is another benefit of YCA eradication.

The above analysis does not consider the value of avoided losses to residents in a large residential development that recently commenced in the project region, the Mt Peter development. Most of the residential development there has not yet happened and therefore, would not be accounted for in the 2016 ABS Census. To estimate the future value to householders in the Mt Peter area, an estimate was obtained from a developer in the area (Adam Gowlett of Ken Frost Homes) of the number of households and residents expected to reside there over the period of analysis (2018-2038). Since YCA is already present in the area it was assumed that the area would remain infested over the analysis period if the YCAEP is discontinued. Projected dwelling numbers in the Mt Peter development are assumed to increase by 922 per year for 20 years, eventually reaching 18,444 at the end of the analysis period, in line with the projections provided by one of the development companies involved.

Valuing benefits to Australian tourists

One of the questions that must be addressed in a cost benefit analysis is whose benefits are to be considered (who has "standing") (Boardman *et al*. 2017; OBPR 2016). In this analysis, benefits are considered for Australian citizens but not international visitors to the project region. It is possible that YCA spread would result in a decline in international visitors and consequently cause losses to Australian-owned businesses that derive income from international visitors. This is not considered in this analysis due to data and time constraints. Data were not available on the extent to which YCA would be controlled by the tourism industry and government agencies, nor the sensitivity of tourist visitor numbers to the risk of contact with biting insects. In the absence of this information, the primary focus of our estimation of tourism impacts was on losses to Australian tourists who would continue to visit the region despite the presence of YCA. Impacts of YCA on Australian visitors to the study region were estimated based on the total number of annual visitors and an estimate of their WTP to avoid contact with YCA. The latter information is not known but was estimated based on the study of Akter *et al*. (2015), who estimated Australian householders' WTP to reduce their risk of contact with invasive ants, including YCA. The Akter et al. (2105) study estimated the value to households of reducing their risk of contact with invasive ants, whereas the present analysis considers individual tourists rather than households. It can reasonably be assumed that an individual would derive a smaller benefit than a household comprising multiple individuals, from reduced risk of contact with YCA. Households surveyed by Akter et al. (2015) could reasonably be interpreted to face the prospect of ongoing risk of contact with YCA, whereas visitors to the project region face this risk only for the duration of their visit. These differences between visitors to an infested region and residents of that region were accounted for in this analysis by considering smaller values of visitor WTP to avoid contact with YCA. The per-visitor value considered was conservatively set at $24/visit. This is 25%, and 8%, of the Akter et al. (2015) estimates of household WTP to reduce the risk of contact with YCA from high to medium and high to low, respectively. This value of $24/person/visit is approximately half the WTP estimated by Mwebaze *et al*. (2010) for international tourists visiting the Seychelle Islands to eliminate invasive species from the islands, including YCA. Tourist losses were estimated without the YCA spread model. This reflects that YCA already is present at or near popular tourist destinations, including Kuranda and Cairns (and much of the Atherton tablelands) which implies that tourists would derive benefits from eradication as soon as the program extension commences, without the need to consider precise locations of future YCA spread.

Valuing benefits from protecting the environment

The failure to eradicate YCA in the study region would not only affect residents living there and tourists visiting there, but also people living elsewhere in Australia who value the region's biodiversity. This benefit is a form of existence value, which is a benefit to people from their knowledge that biodiversity will continue to exist over the long-term future. Existence values can be substantial because of the large number of people who may obtain these values.

In this analysis, the environmental benefits of eradicating YCA in and near the WTWHA are estimated based on the findings of a previous study that estimated Australian householders' WTP to avoid extinctions of threatened species (Akter *et al*. 2015). It was estimated that people who placed a high value on biodiversity would be willing to pay approximately $47/household on average, to avoid the extinctions of seven native species. People in a second demographic group were identified that placed a lower value on biodiversity. The latter segment of survey respondents were estimated to be willing to pay approximately $8/household on average, to conserve seven species. Implicit in the study's findings was that householders' WTP for conservation was linear in the number of species conserved, implying, for example, that people in the high value group would be WTP twice as much to conserve double the number of species. The number of native species that would be conserved by eradicating YCA within and near the WTWHA is not known, and, therefore, the assumption made here that eradication of YCA would conserve at least seven species should be viewed with some caution. However, YCA have been formally listed as Key Threatening Processes on both Christmas Island and for New South Wales, and have been implicated in the extinctions of the Christmas Island pipistrelle and Christmas island forest skink.

It is assumed that WTMA will continue to suppress YCA within the WTWHA to protect key ecological assets. If this occurs, it may reduce the number of species likely to be threatened by YCA.

Household WTP and household numbers used in this analysis are listed in Table 4.

Valuing benefits from protecting the environment are focussed on the Choice modelling study and WTP measures are based on the number for species conserved. While this provides a justifiable indicator and a method of monetarising benefits there is a need to acknowledge there are other, significant but difficult to quantify environmental costs of YCA. It is acknowledged that YCA infestations, like many other invasive tramp ants will result in losses to ecosystem services not only due to the direct decline in species diversity and abundance but also indirect changes as a result of altered species (particularly invertebrate species) distribution and abundance leading to changes in ecosystem webs, loss of pollination services, the lack of seed dispersal, and so on. While these impacts are hard to quantify and have been excluded from the CBA metrics the potential for knock on effects in a system as complex and interconnected as the Wet Tropics rainforest is very high. In short, this CBA remains highly conservative in estimating the environmental benefits of protecting the environment, and should be interpreted in that way.

Valuing benefits to agricultural producers in the project region

The agricultural industries considered were sugar cane, tree fruits, plantation fruits and beverage and spice crops (including coffee), defined according to Australian Land Use and Management Classification System (ALUM) (ABARES 2016). Locations of these industries were identified with a digitised map of national land uses (ABARES 2017). It was necessary to align this land use map with the grid representation of the study region considered in the YCA spread model. For those grid cells containing more than one ALUM land use, the use occupying the largest area within the cell was recorded as the sole land use in that cell.

Complete national records of industry locations made with the ALUM classification system are available only for aggregated industry groupings rather than individual industries. For example, spatial locations of lychee producers in Queensland are not available at a fine spatial resolution, but records are available for tree fruits as a whole at a fine resolution. The ALUM classification of tree fruit industries includes pome fruits, stone fruits, and various tropical fruits such as mangoes and bananas. These different tree fruits may be differentially susceptible to YCA-induced yield losses. Any such differences in yield losses between industries, if they exist, cannot be captured with the ALUM industry classification. Other datasets using different industry classifications are available, but those datasets have a substantially coarser spatial resolution, which is another source of error in estimating YCAEP benefits.

Numerous sources (e.g., Biosecurity Qld 2012 and 2016; Department of Environment and Heritage 2006) indicate that YCA have direct impacts on some crops through undermining roots but also considerable indirect impacts through YCA tending sap-sucking insects that help encourage secondary infestations of sooty moulds and blights that result in yield losses or cause market rejection of fruit. A previous CBA of the Biosecurity Queensland-managed YCAEP (Biosecurity Queensland 2012) estimated losses of between 20 and 40% of bananas and lychees and losses of mangoes and paw paws of 5-10%. Coffee, coconuts, cocoa and macadamia nut crops have all been cited as at risk of YCA impacts. Due to the lack of good verified data in the Wet Tropics region to quantify yield losses due to YCA, and in the interests of simplicity the potential for these impacts are noted but not included in the CBA metrics. This assumption is likely to result in a conservative benefit-cost ratio.

The cost of YCA would be similar across industries if most of the yield impacts of YCA could be avoided by pesticide application. It is assumed in this analysis that industry losses in all industries other than sugar cane will solely take the form of additional control costs, with no yield losses. The same simplified assumption was made in the only known previous CBA of a similar YCA eradication programmes (Biosecurity Queensland 2012), although in that study, it was assumed in the "without YCAEP" scenario that the fruit-growing industry, sugarcane and coffee industries would maintain YCA-freedom by applying three treatments of S-Methoprene per year. The main change made in the present analysis was to assume that a different, more effective treatment method would be applied involving three applications of Antoff per year, similar to the method currently applied in the YCAEP. However, this assumption should be viewed with caution because there is uncertainty whether Antoff will be able to be widely used by growers, primarily due to the fact that it is an unregistered product and requires an APVMA permit. There are currently a restricted number of registered products for control of YCA, and most of these products currently require a permit to allow for "off-label" use in selected agricultural applications. regulatory approval is required for fipronil-based pesticides to be used in agricultural enterprises. A small number of producers who were surveyed by WTMA for this analysis indicated that the fipronil-based pesticide Regent 200SC is used in the industry. However, it is not known how widespread is its current use or whether it would be used by more producers if YCA spreads. Antoff, if registered, could potentially be used in select agriculture situations if there is a suitable method of distributing it over large areas. Antoff is currently applied by the YCAEP with an aerial broadcast method but this option may not be readily available or cost-effective for individual sugar cane producers.

The data available for this analysis potentially allows for yield losses to be considered in the sugar cane industry. Different scenarios could potentially be considered. In one scenario, all yield losses would be prevented by applying a fipronil based pesticide. The assumption in this scenario that pesticide application will prevent all or most yield losses reflects advice provided by an external scientific advisor to the YCAEP consulted for this analysis (Dr. Ben Hoffmann, CSIRO) that adequate application of Antoff would result in very low numbers of YCA and may potentially remove YCA from treated areas. The cost of Antoff to cane growers is not precisely known because it is not commercially available, however, is estimated here at $300/ha/year based on 3 treatments at a 5kg/ha application rate (Gareth Humphreys, Operations Manager, WTMA, personal communication). Pesticide costs are likely to be substantially smaller than the cost of yield losses that would be avoided by applying an effective pesticide treatment. One of the producers surveyed for this analysis indicated that without an effective pesticide, YCA induced yield losses would be 40%. This is worth approximately $2,085/ha at the 2018 harvest pool price ($369/tonne), based on an estimate of the weighted average sugar yield in far north Queensland of 14.13 tonnes/year (Collier and Holligan, 2016, Table 4). A previous cost-benefit analysis of the Biosecurity Queensland-managed YCAEP considered a lower yield loss of 14% (Biosecurity Queensland 2012) based on an estimate provided by a single producer. Neither of these estimates have been independently confirmed. The larger of these yield loss estimates, of $2,085/ha, should be viewed with caution because the grower who provided this estimate stated that a yield loss of this magnitude would prevent profitable sugar cane production. This implies that if YCA cannot cost-effectively be controlled in sugar cane land, the land would be sold to the next best alternative land use. The resulting declines in land values are not known and have not been estimated for this analysis. It is possible that the decline in land value will be substantially smaller than 40% if, for example, YCA can be controlled more cost-effectively under alternative land uses. Reflecting this uncertainty about the cost of yield losses, and the likelihood that most or all yield losses can be prevented by pesticide application, yield losses are not considered in the estimation of eradication benefits reported in A summary of biophysical impacts and monetary values of uncontrolled YCA spread, which would be avoided by eradicating YCA, is provided in Table 5. YCAEP performance metrics, which take into account not only the benefits of eradication but also the costs, are reported in Table 6.

Table 5 and Table 6.

Losses to sugar cane producers occur when YCA reaches grid cells containing cane farming land. Since the YCA spread model is stochastic, there is variation in the spread process between different simulation runs, and consequent variation in the locations and timing of impacts. In this analysis, industry impacts are measured as the product of the likelihood of occurrence of YCA and the magnitude of impacts where YCA is present. The likelihood of YCA occurrence at a specific grid cell in a specific year is the proportion of the 50 simulation runs in which the cell was occupied by YCA in that year. For each cell, the average YCA occupancy rate in each year was then multiplied by industry losses arising from YCA presence.

Choice of discount rates

In the baseline analyses, industry losses are discounted at a rate of 7% to estimate the present value of losses. This is the baseline discount rate recommended for national cost-benefit analyses by the Office of Best Practice Regulation (OBPR 2016). As part of sensitivity analysis, we follow the guidelines set out in OBPR (2016) by considering a lower discount rate of 3%. The importance of considering lower discount rates than 7% reflects two main considerations. First, a 7% rate may overstate the true opportunity cost of government funds because the Australian Government borrowing rate, which is one of the components of the discount rate, is between 1% and 2%, much lower than 7%. Second, underestimating the appropriate discount rate can result in substantial underestimation of eradication benefits relative to eradication costs because benefits are obtained over the long-term future whereas costs are incurred only over the near future. In addition to these reasons for considering a lower discount rate, the 7% rate recommended for use in Australian Government funded projects is much higher than the rate recommended for projects whose primary purpose is conservation of the environment over the far distant future (Weitzman 2001).

Results

Results of the spread modelling for the baseline scenario are illustrated in Figure 3 and are summarised in Table 5. Key assumptions of the baseline scenario were discussed above and are summarised in footnotes to Table 5.

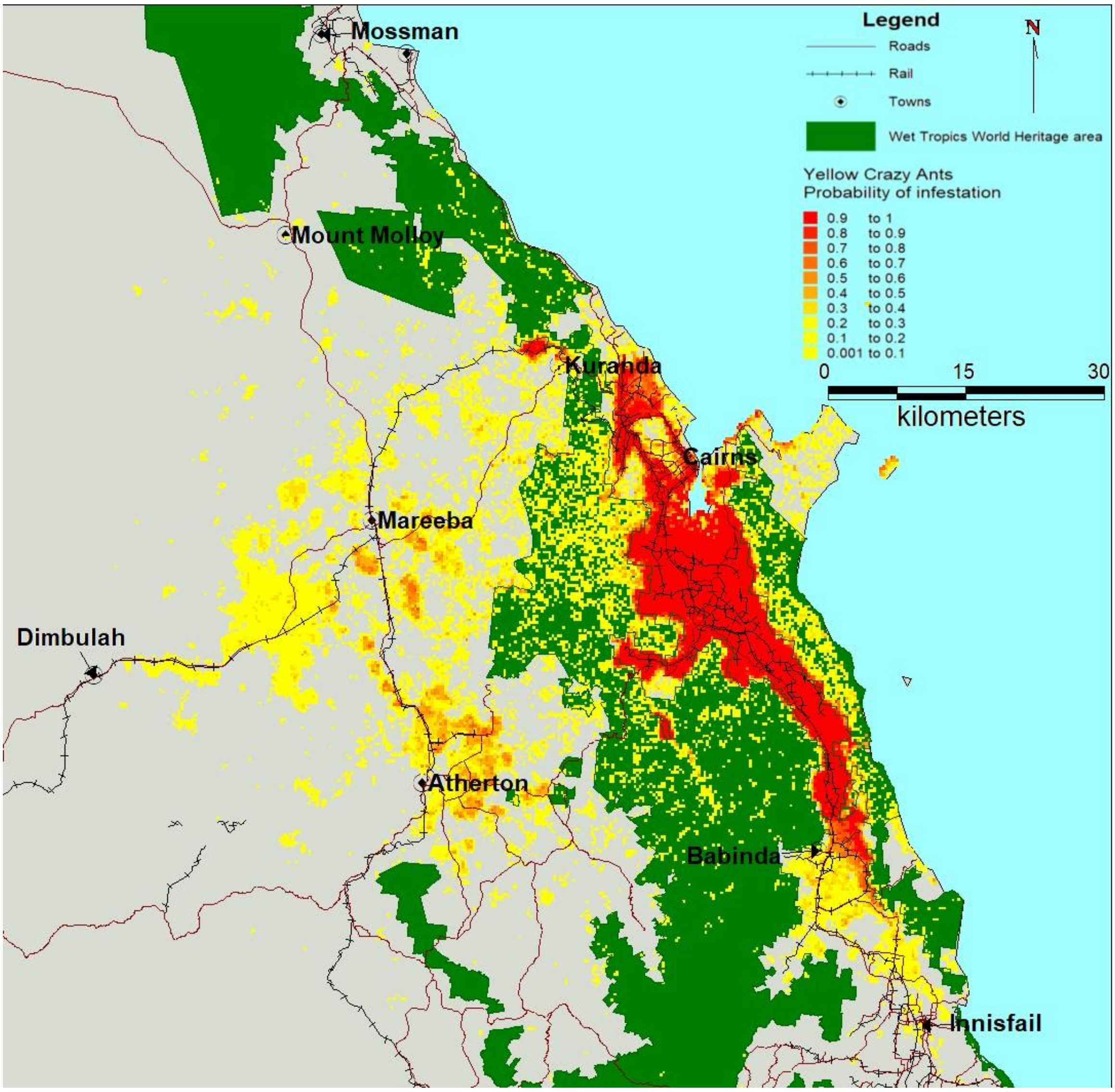

Figure 3: Spatially explicit probabilities of YCA infestation

Figure 3 illustrates spatially explicit probabilities of YCA infestation based on the proportion of simulation runs in which the sites were occupied by YCA over 30 years. Red sites have the largest probability, yellow sites have the lowest probability, and orange sites have intermediate probabilities. It can be seen that although most of the YCA invasion occupies areas of human habitation and agricultural land, large areas of the WTWHA are at risk of becoming occupied. These sites are scattered over much of the WHA, and would provide foci for subsequent spread over most or all of the WHA.

A summary of biophysical impacts and monetary values of uncontrolled YCA spread, which would be avoided by eradicating YCA, is provided in Table 5. YCAEP performance metrics, which take into account not only the benefits of eradication but also the costs, are reported in Table 6.

Table 5: Impacts on residents, domestic visitors, agricultural industries and biodiversity

Benefit category	Impacts in 30 years	Present value ($M) 7% discount rate	Present value ($M) 3% discount rate
Regional residents[1]	158,829 people	$212.3	$332.3
Regional industries[2]			
Tree & plantation fruits, beverage and spice crops	943 ha	$0.3	$0.8
Sugar cane	24,645 ha	$25.0	$52.1
Domestic visitors[3]	1,920,000 people	$310.3	$476.8
Total benefits (non-environmental)		$547.9	$862.0
Total benefits (including Environmental benefits)		$6,173.4	$9,793.4

1. It is conservatively assumed that there will be no population growth outside Mt Peter, and that dwelling growth in Mt Peter will be 922 dwellings per year up to 2038, based on forecasts provided by the developer. If any population growth will occur outside Mt Peter, eradication values would be larger than estimated here. In the absence of information on population growth in Mt Peter after 2038, no further growth is assumed to occur there after this date. NPV is calculated as sum of home pesticide costs (based on a previous estimate reported in Biosecurity Queensland 2012) and household WTP to avoid risk of contact with YCA outside the home (based on the survey of Akter et al. (2015).
2. Assumes cane and horticulture industries would use Antoff to avoid all yield losses, at $300/ha. This parameter should be viewed with caution because widespread application of Antoff in those industries may not gain regulatory approval or there may be logistical impediments to delivering Antoff over large areas. A small survey of cane growers indicated that some would use the pesticide Regent 200SC at $80/ha. This would reduce avoided pesticide costs in agriculture, as discussed in the text. Regulatory approval would be needed for either form of fipronil-based pesticide, and it is not certain that such approval would be granted. The assumption that effective pesticides would be available should therefore be viewed with caution.
3. Source: TTNQ 2018. Assumes no growth in visitor numbers, and each visitor is WTP $24 to prevent YCA spreading throughout tourist areas.

Table 6: YCAEP performance metrics

	Net present value ($M)	Benefit-cost ratio
Eradication cost[1]		
7% discount rate	34.6	
3% discount rate	38.5	
Including environmental benefits		
7% discount rate	6,138.8	178.4
3% discount rate	9,754.9	254.3
Excluding environmental benefits		
7% discount rate	513.3	15.8
3% discount rate	823.5	22.4

1. Estimates are based on an undiscounted annual cost of $6 million over 7 years, commencing immediately. The estimate was provided by WTMA.

The YCAEP has a very large estimated net present value (NPV), and benefit-cost ratio (BCR), in the baseline scenario of approximately $6.1B, and 178:1, respectively, at a 7% discount rate. These values increase to $9.7B, and 254:1, respectively at a 3% discount rate. The large magnitude of these values reflects the high species richness of the WTWHA, the vulnerability of many species there to YCA spread (Lach and Hoskin 2015) and the willingness of Australian households to pay a substantial sum to protect native species from extinction. This result also reflects an assumption, based on expert opinion, that efforts to protect native species in the "without YCAEP" scenario will be unable to prevent native species extinctions. This is illustrated by the Kuranda tree frog (Litoria myola), which is listed as critically endangered in the IUCN Red List, and endangered under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). YCA has been identified as one of the main threats facing the frog, reflecting that YCA has become established at one of its few known breeding areas (Lach and Hoskin 2015). The environmental benefits of YCA eradication not only reflect avoided native species extinctions but also avoided harm to ecosystems. YCA can substantially disrupt ecosystems through processes such as direct predation and harassment of native species, reduction in abundance of invertebrate prey, disruption of pollination and seed dispersal, and indirect effects arising from ecological interdependencies within the WTWHA.

The household survey on which the environmental values are based (Akter et al. 2015) elicited from households their willingness to pay (WTP) to conserve 7 native species. The precise number of native species likely to be protected by eradicating YCA in the

Wet Tropics is not known, but based on our review of relevant published studies, it is assumed in the baseline scenario that at least seven native species would be protected by eradicating YCA. This assumption can be viewed as conservative given the possibility that YCA would cause larger numbers of extinctions.

Most of the non-environmental benefits of eradication are to tourists, with substantially smaller but significant benefits to regional residents. Benefits to agricultural industries are much smaller than benefits to regional residents. This reflects that YCA is likely to impact large numbers of residents in the project region, and that agricultural losses can potentially be mitigated by pesticide application.

There is substantial uncertainty about the effectiveness of protection measures that would be undertaken in the "without YCAEP" scenario. A leading international expert in YCA biology and management consulted for this analysis (Dr Ben Hoffmann, CSIRO) indicated that prevention of substantial ecological losses would ultimately become infeasible once YCA becomes widely established within the WTWHA. YCA is readily spread by people from locations where people live, work or visit. The WTWHA is not only a globally significant biodiversity hotspot but also a popular tourist destination, which increases the risk of human assisted spread of YCA within the WHA. Although YCA is likely to occupy much of the WHA over the long term if eradication efforts cease, control efforts may nonetheless be undertaken to mitigate ecological losses. The effectiveness of these efforts will depend partly on the control methods available. The most effective pesticide used to date in the YCAEP is a fipronil-based pesticide (Antoff) but the application of Antoff over large areas of the WTWHA may not receive regulatory approval due to potential adverse environmental effects. If approval is not granted and less effective control methods are consequently applied, YCA impacts on the WHA would be larger. This would result in larger environmental benefits of eradication because the effectiveness of WTWHA protection efforts in reducing species extinctions is one of the main determinants of the benefits of eradication (if fewer species extinctions can be prevented in the absence of eradication, the benefits of eradication would be larger).

Even if environmental benefits are not considered, the non-environmental benefits are substantially larger than the estimated cost of eradication, resulting in an estimated NPV and BCR of $513M, and 16:1, respectively, at a 7% discount rate. These values increase to $823M, and 22:1, respectively, when the discount rate is reduced to 3%. The substantial magnitude of these values reflects that many residents are likely to be affected by YCA within 20 years. YCA already is present at a large planned residential development in the Mt Peter area. It is also likely that YCA will affect large numbers of tourists, reflecting that YCA is already present near popular tourism destinations at Cairns and Kuranda.

It is possible that residents will experience larger losses per person than tourists because they will have to live with YCA, whereas tourists will experience only a transient risk of contact with YCA. However, the number of tourists that visit the region substantially exceeds the number of residents. Either there would be a large reduction in tourists, which would cause losses to the tourism industry, or tourists would continue to visit the Wet Tropics region without a large decline in visits. In the latter scenario, the cost of YCA would potentially be shared by tourists and the tourism industry. Tourists would experience nuisance costs from contact with YCA and industry would bear costs of controlling YCA within tourist accommodation and possibly also tourism attractions. The final allocation of costs would depend on factors such as whether the tourism industry passes on costs to tourists in the form of higher prices, or whether some of the costs would be borne by government agencies such as WTMA. In this analysis, the only cost considered to tourists is the nuisance cost of the risk of exposure to YCA. Insufficient data were available to estimate other potential costs to tourists or the tourism industry.

Collectively, impacts of uncontrolled YCA spread on residents and domestic tourists are likely to substantially exceed impacts on agriculture because of the large number of people affected and large losses per resident. However, further information is required to confirm that sugar cane growers will not experience large yield losses, which could potentially arise if fipronil application is prevented by regulatory measures to avoid fipronil runoff from large areas of land to the Barrier Reef lagoon. For this and other reasons, it is unclear whether cane industry impacts will largely be experienced as additional pesticide costs or yield losses. In the event that yield losses are substantial, they could prevent profitable sugar cane production by affected growers. A small sample of growers consulted for this analysis indicated that yield losses could potentially prevent profitable cane production. If this occurred, sugar producers would eventually be forced to either sell their land or change land uses to limit losses. This possibility is not considered here because of a lack of information on the value of the next best alternative land uses.

Despite this uncertainty about sugar cane impacts of YCA, it is likely that the largest impacts of YCA will be on residents, tourists and the environment. Horticulture sector impacts are likely to be much smaller than sugar cane impacts, partly because horticulture enterprises are more distant than sugar cane enterprises from current YCA infestations. The horticulture industries considered in this analysis, tree fruits, are located primarily in the Atherton Tablelands, which experiences smaller areas of YCA infestation within the modelled time horizon.

The large adverse impact of YCA on residents reflects that homes would require ongoing pesticide treatment, at a cost of hundreds of dollars per year. It also reflects that households would experience further losses from YCA through an increased risk of contact with the species in the immediate vicinity of their homes. A large planned residential development, at Mt Peter, is in a currently infested area, and spread through Cairns would affect large number of additional households. The Mt Peter development will contribute substantially to the estimated future impact of YCA on residents because of the large size of the development and its close proximity to a current YCA infestation.

Cost of protecting the WHA

A requirement of this cost-benefit analysis is to assess alternative options for protecting the WTWHA. This helps to inform the decision on whether to continue with eradication efforts or to focus on protecting the WTWHA without eradicating YCA from the region. Information to help make this decision includes estimates of the cost and effectiveness of ongoing protection efforts, and a comparison of protection costs with eradication cost. In this report, we focus on providing an initial approximate estimate of protection costs and an initial assessment of whether protection will cost more than eradication.

Simulation analysis

The aim of this analysis is to estimate the cost of protecting the WTWHA over a 30-year horizon. Protection would continue beyond this horizon, and this analysis indicates that costs will increase substantially beyond 30 years.

The cost of suppressing YCA infestations within the WTWHA is estimated under the assumption that suppression efforts will be focused on treating known infestations that are detected passively by community members. It is assumed in this scenario that suppression efforts will reduce YCA abundance without slowing its spatial spread. Reasons for this assumption include the likelihood that new YCA infestations will be discovered after a substantial delay due to the absence of active monitoring, and the possibility that regulatory constraints will prevent application of the most effective treatment method due to concerns about non-target ecological impacts. In particular, the pesticide fipronil, which is the main treatment method used in the YCAEP, is highly toxic for crustaceans (Al-Badran et al. 2018), insects and fish (Zhang et al. 2018), and many other species including bees, termites, and particular species of birds and lizards. An alternative treatment method based on s-methoprene, an insect growth regulator, is believed to have smaller harmful impacts on non-target species. However, an independent review of the YCAEP noted that previous applications of s_methoprene had been ineffective in eradicating YCA, and provided little more than a temporary knock-down in numbers.

The approach taken was to record the number of grid cells within the WTWHA that become occupied by YCA over the modelled horizon in the simulations conducted for the “no YCAEP” scenario. The cost of treating each occupied cell over time over the next 30 years, at $300/ha, is illustrated in Figure 4.

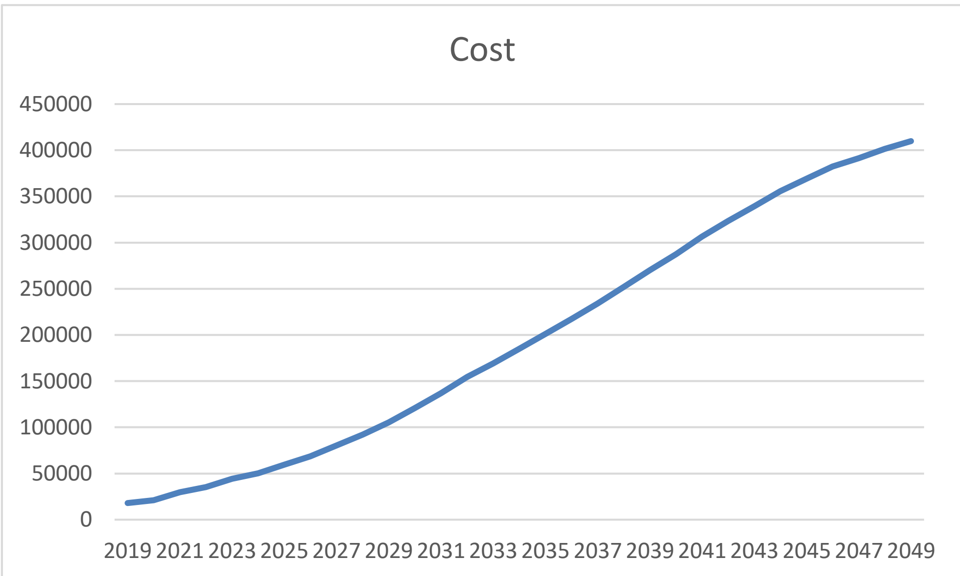

Figure 4: Estimated cost of treating all occupied grid cells over time

Figure 4 illustrates that spread within the WHA is estimated to increase substantially in approximately 10 years. The estimated cost of treating these grid cells increases to over $400,000/year in 30 years.

Discussion

Accounting for uncertainty in cost-benefit analysis of the YCAEP

The main sources of uncertainty about the YCAEP's costs and benefits identified in this analysis related to the magnitude of tourism and environmental values. These are potentially the largest benefits of eradication because of the large number of tourists who visit the region and the susceptibility of the region's biodiversity to YCA spread. Points and qualifications to consider include:

- Uncertainty about the tourism impacts of YCA spread in this analysis reflects the use of a previous household survey instead of a survey specifically of tourists to the project region.
- The value of environmental benefits depends on the number of species conserved by eradicating YCA in the project region, which is not yet known. Expert opinion could be elicited to determine an approximate number of species likely to be conserved by successful completion of the YCAEP. Opinion would also need to be elicited to estimate the likely impact of WTWHA protection efforts in the "no YCAEP" scenario. If these efforts can help to prevent extinctions, this would reduce the value of eradication.
- Uncertainty about the value of environmental benefits also reflects uncertainty about whether discontinuation of the YCAEP would result in Australia having to downgrade the WHA status in response to losses caused by YCA spread, and the cost to Australia if this occurs. Reducing this uncertainty will require consultation with ecologists that have expertise in YCA biology and local ecosystems, and consultation with government personnel involved in WHA management.

That said, the preliminary CBA conducted in this report is robust if not conservative in estimation. In particular, it is not unusual in studies like this to include households' WTP even if they are not currently and directly affected by YCA. We've left this effect, which would be substantial, out. We've also taken a very conservative estimate of the WTP by tourists.

References

ABARES (2016). The Australian land use and management classification version 8. Canberra, ACT. Accessed on 17 August 2018 at http://www.agriculture.gov.au/abares/aclump/Documents/ALUMCv8_Handbook4edn Part2_UpdateOctober2016.pdf

ABARES (2017). Catchment scale land use of Australia— Update September 2017. Accessed at: http://data.daff.gov.au/anrdl/metadata_files/pb_luausg9abll20171114_11a.xml

Akter, S., Kompas, T. and Ward, M.B., 2015. Application of portfolio theory to asset-based biosecurity decision analysis. Ecological Economics, 117, pp.73-85.

Al-Badran, A. A., Fujiwara, M., Gatlin, D. M., & Mora, M. A. (2018). Lethal and sub-lethal effects of the insecticide fipronil on juvenile brown shrimp Farfantepenaeus aztecus. Scientific reports, 8, 10769.

Australian Institute of Family Studies (AIFS) (undated) Households in Australia. Accessed on 25/11/2018 at: https://aifs.gov.au/facts-and-figures/households-australia/households-australia-source-data

Biosecurity Queensland (2012). Cost Benefit Analysis of Yellow Crazy Ant Eradication in Queensland. Unpublished report.

Biosecurity Queensland (2016). Invasive animal risk assessment - Yellow crazy ant (Anoplolepis gracilipes) at https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/63372/IPA-Yellow-Crazy-Ant-Risk-Assessment.pdf

Bradhurst, R.A., Roche, S.E., East, I.J., Kwan, P., & Garner, M.G. (2015). A hybrid modeling approach to simulating foot-and-mouth disease outbreaks in Australian livestock. Frontiers in Environmental Science, 3, 17.

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2017). Cost-benefit analysis: concepts and practice. Cambridge University Press.

Bos, M.M., Tylianakis, J.M., Steffan-Dewenter, I. and Tscharntke, T. (2008). The invasive Yellow Crazy Ant and the decline of forest ant diversity in Indonesian cacao agroforests. Biological Invasions, 10(8), pp.1399-1409.

Collier, A., Holligan, E. (2016). FEAT Regional Scenarios: Economic Analysis. Department of Agriculture and Fisheries (DAF), Queensland.

Council of Australian Governments (COAG) (2012). National Environmental Biosecurity Response Agreement (NEBRA), viewed November 2018 at https://www.coag.gov.au/sites/default/files/agreements/National-Environmental-Biosecurity-Response-Nov-2012.pdf .

Department of Environment and Heritage (2006) Threat abatement plan to reduce the impacts of tramp ants on biodiversity in Australia and its territories at http://www.environment.gov.au/system/files/resources/f120c0f6-5bf4-4549-b087-8e53864b315b/files/tramp-ants.pdf

Dodd, A. J., McCarthy, M. A., Ainsworth, N., & Burgman, M. A. (2016). Identifying hotspots of alien plant naturalisation in Australia: approaches and predictions. Biological invasions, 18(3), 631-645.

Garming, H., & Waibel, H. (2009). Pesticides and farmer health in Nicaragua: a willingness-to-pay approach to evaluation. The European Journal of Health Economics, 10(2), 125-133.

Hof, J., Bevers, M., & Kent, B. (1997). An optimization approach to area-based forest pest management over time and space. Forest Science, 43(1), 121-128.

Hoffmann, B.D., Loquat, G.M., Bullard, C., Holmes, N.D. and Dunlin, C.J. (2016). Improving invasive ant eradication as a conservation tool: a review. Biological Conservation, 198, pp.37-49.

Lach, L. and Hoskin, C., (2015). Too much to lose: Yellow crazy ants in the wet tropics. Wildlife Australia, 52(3), p.37.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M., (2000). 100 of the world's worst invasive alien species: a selection from the global invasive species database (Vol. 12). Auckland: Invasive Species Specialist Group.

Mwebaze, P., MacLeod, A., Tomlinson, D., Barois, H., & Rijpma, J. (2010). Economic valuation of the influence of invasive alien species on the economy of the Seychelles islands. Ecological Economics, 69(12), 2614-2623.

O'Dowd, D.J., Green, P.T. and Lake, P.S., (2003). Invasional 'meltdown' on an oceanic island. Ecology Letters, 6(9), pp.812-817.

Office of Best Practice Regulation (OBRP) (2016). Cost-Benefit Analysis Guidance Note. In: Department of Prime Minister and Cabinet (ed.). Canberra: Department of Prime Minister and Cabinet. Accessed at: https://www.pmc.gov.au/sites/default/files/publications/006-Cost-benefit-analysis.pdf

Plentovich, S., Eijzenga, J., Eijzenga, H. and Smith, D., (2011). Indirect effects of ant eradication efforts on offshore islets in the Hawaiian Archipelago. Biological Invasions, 13(3), pp.545-557.

Sarty, M., Abbott, K.L. and Lester, P.J., (2006). Habitat complexity facilitates coexistence in a tropical ant community. Oecologia, 149(3), pp.465-473.

Spring, D., & Kompas, T. (2015). Managing risk and increasing the robustness of invasive species eradication programs. Asia & the Pacific Policy Studies, 2(3), 485-493.

Summerson, R., Hester, S., Graham, S. (2018) Methodology to guide responses to marine pest incursions under the National Environmental Biosecurity Response Agreement. CEBRA Project 1608E: Final Report. Accessed online at: https://cebra.unimelb.edu.au/__data/assets/pdf_file/0011/2826155/CEBRA-1608E-Final-Report-for-webpage.pdf

Tisdell, C. and Wilson, C., 2004. The public's knowledge of and support for conservation of Australia's tree-kangaroos and other animals. Biodiversity & Conservation, 13(12), pp.2339-2359.

Tisdell, C., Wilson, C. and Nantha, H.S., 2005. Policies for saving a rare Australian glider: economics and ecology. Biological Conservation, 123(2), pp.237-248.

Tourism Tropical North Queensland (TTNQ) (2018). TOURISM FACT FILE, National Visitor Survey, Year Ending March 2018. Accessed on 25 November 2018 at: https://tourism.tropicalnorthqueensland.org.au/wp-content/uploads/2018/07/Final-Mar18-NVSDrive_InfoGraphics_TourismFacts.pdf

Weitzman, M.L., (2001). Gamma discounting. American Economic Review, 91(1), pp.260-271.

Young, G.R., Bellis, G.A., Brown, G.R. and Smith, E.S.C., 2001. The crazy ant 'Anoplolepis gracilipes' (Smith) (Hymenoptera: Formicidae) in East Arnhem Land, Australia. Australian Entomologist, The, 28(3), p.97.

Zhang, Bo, et al. (2018). "Interactions of Fipronil within Fish and Insects: Experimental and Molecular Modeling Studies." Journal of agricultural and food chemistry 66: 5756-5761.