An independent review of bell miner associated dieback

Report prepared for the Project Steering Committee: Systematic Review of bell miner associated dieback (BMAD)

FINAL REPORT

June 2017

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Acknowledgements

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Executive summary

Background

Bell miner associated dieback (BMAD) is listed as a key threatening process under the NSW *Threatened Species Conservation Act* (OEH, 2016) and is known to directly impact threatened vegetation communities (e.g. Blue Gum High Forest ecological community) by leading to a loss of habitat for native flora and fauna (OEH, 2016). It is one of many processes that result in forest dieback in Australia.

The NSW Office of Environment and Heritage (OEH), on behalf of a consortium of NSW government agencies [Environmental Protection Authority (EPA), Forestry Corporation of NSW, Department of Industry (DoI) and the National Parks and Wildlife Service (NPWS)] engaged independent consultant Knowledge Ecology to conduct a systematic review of the evidence available to inform BMAD management. The aim of the systematic review was to collate existing knowledge about the scale, relative causes and effects of BMAD in NSW and effective management interventions. The review also identified knowledge gaps.

Review methodology

The Project Team used various methods to collate data for addressing the review questions, including literature searches, a survey of practitioners and researchers, and GIS analysis. Different approaches were then used to synthesise the data where appropriate; the key products being a BMAD causal model, intervention case studies and a spatial extent map. Each product is the result of combining evidence from multiple sources.

The BMAD causal model is based on 115 studies identified from the literature search. Individual relationships within the model are linked to specific studies and an assessment of uncertainty is provided for each relationship in the model.

Review findings

The current evidence base supports the existence of a mechanism whereby dense Bell miner colonies facilitate sustained psyllid infestations that lead to dieback. The catalyst for this pathway is superior nesting habitat for the Bell miner, which results in dense colonies that exhibit intra-specific aggression to exclude other avian psyllid predators. Human activities that lead to increases in understorey density, often via woody weed invasion, are heavily implicated in this process. Once this improved habitat is available, the Bell miner has various strategies for rapidly increasing population numbers, since under normal conditions nestling mortality rates are very high.

The BMAD causal model provides an explanation for cases where Bell miners exist but BMAD does not, and it explains why BMAD can occur in undisturbed settings. However, as with all questions in this review, further research is required to reduce the uncertainty around some relationships in the causal model.

There is a serious lack of scientific studies relating to the effectiveness of BMAD interventions. Only 15 cases could be identified from the scientific literature. Even so, there is enough consistency across all 20 case studies from the literature and anecdotes to suggest that managing Bell miner populations will indeed have an impact on psyllid infestations and subsequent dieback when BMAD is the cause.

Encouragingly, management techniques to manage woody weeds, such as splatter guns for herbicide, have been tested and proven to be both effective and relatively cheap, even at large scales. Given these advances in treatment, it is perhaps no longer reasonable to suggest that cost prohibits BMAD treatment when compared to the costs of non-treatment, particularly as a preventative measure. For example, lantana has been shown to dramatically reduce post-harvest natural regeneration, affecting the economic sustainability of timber harvesting operations.

Until very recently the extent of BMAD in NSW has not been accurately understood. A Department of Primary Industries – Forest Science aerial mapping program is beginning to provide reliable data, however, at the time of writing this report analysis of the data is ongoing. Mapping has been undertaken across approximately 1,000,000 hectares in northern NSW and other susceptible areas of NSW need to be mapped using the same process.

Review recommendations

The review proposes a set of recommendations that relate to:

1. improving the evidence base associated with reducing important remaining uncertainties
2. management practices based on the current evidence base
3. infrastructure to assist practitioners learn and apply current knowledge.

Recommendations are listed here for each review question.

Recommendations: What causative factors lead to BMAD? (Q1)

R1(a): That the causal model presented in Section 2 of this review be adopted as a working hypothesis of BMAD in NSW.

R1(b): The causal model be established in an online setting where it can be readily updated and contributed to.

R1(c): A BMAD research and development program be established to answer a series of questions in a logical sequence to derive best practice management. The top priority for R&D investment should be to rigorously test the causal model that has been developed for this review.

Recommendations: What are the economic, social and ecological impacts of BMAD? (Q2)

R2(a): An analysis be conducted to assess the overlap of DPI BMAD mapping with threatened flora and fauna in NSW.

R2(b): An analysis be conducted to assess the economic impact of BMAD on forestry operations in NSW State-owned forests. Note this should be linked to the research proposed in R4(a).

Recommendations: What are the most effective management interventions to control, prevent and restore BMAD? (Q3)

Management recommendations

Evidence drawn from intervention case studies and the causal model provide a basis for the following practice recommendations. These recommendations should be regularly reviewed taking new evidence into consideration.

Prevention

For any activity* that disturbs susceptible vegetation communities:

R3(a): Disturbance of the canopy should be minimised where possible.

R3(b): Where the canopy is disturbed, rehabilitation should focus on re-establishment of a canopy as soon as possible to limit unnatural understorey density.

R3(c): Site rehabilitation should include ongoing management of invasive weeds, particularly those that minimise natural regeneration and can act as superior nesting sites for Bell miners. Note that in harvesting operations weeds such as lantana have been shown to dramatically impact on the economic viability of sites so improved management of weeds will not necessarily lead to a net negative financial outcome.

R3(d): Exclusion of fire is an artificial disturbance activity that can lead to woody weed invasion. Appropriate fire regimes should be designed and implemented. Note that a significant proportion of BMAD sites would not have had fire at regular intervals so this needs to be carefully implemented using the best available science, with appropriate environmental approvals and liaison with the Rural Fire Service.

*These preventative measures apply to activities that include: harvesting, clearing for roads and infrastructure, recreational activities that alter vegetation, and removal of natural fire regimes.

Treatment

R3(e): A site assessment should be undertaken to ensure that Bell miners are present and psyllid attack is the primary cause of dieback prior to investment in BMAD interventions. There are many other causes of eucalypt forest dieback. See R3(k) for more about development of a site assessment method.

R3(f): If the prevailing vegetation community is naturally dense in the understorey or mid-storey then consideration should be given to not intervening in the site as BMAD may be a natural process there.

R3(g): At sites with an unnatural level of understorey and/or mid-storey density the viability of the seed bank for rehabilitation without planting should be assessed. Many interventions have likely failed due to a lack of a viable seed bank. Sites requiring plantings will cost significantly more than sites without.

R3(h): In sites with high value assets being impacted by BMAD (e.g. threatened flora or fauna) consideration should be given to culling of Bell miners followed by site rehabilitation. This has been shown to have an immediate reduction on exclusion of other bird species for example.

R3(i): The primary aim of site treatment should be to reduce the occurrence of superior nesting sites for Bell miners. The method best to use to achieve this will depend on site-specific characteristics:

- Once lantana is established, only high intensity fire is able to significantly reduce its density over the medium term. There are potential impacts of intense fire on the rehabilitation of native plants including on the seed bank so it is not considered appropriate. Instead see P4 about low-intensity fire for prevention above.
- The use of splatter guns for lantana control on a large scale has been proven highly effective.
- Some cases have shown the potential for weeds such as lantana to maintain its Bell miner nesting benefits even after the plant is dead. This is because the dead canes still provide nesting habitat when the plants have been very dense. In such cases herbicide alone may not have the desired outcome of reducing Bell miner density so mechanical or fire in cooler months may be required as a follow-up to the herbicide application.

Research, development and learning recommendations

R3(j): If there are sufficient funds beyond the causal investigations proposed in section 2, a second line of inquiry related to lantana control could be run concurrently. Regardless of the link between lantana and BMAD, lantana has a significant economic and environmental impact on all land uses that should be minimised. This includes harvesting sites where the evidence clearly shows it impacts on the economic sustainability of harvesting by restricting regeneration of valuable timber. Note this would be relevant for BMAD sites from the Illawarra north, where this weed is established.

It is recommended that a decision tree for the selection of BMAD interventions be developed and then tested and refined using this line of inquiry.

Learning infrastructure

R3(k) Ongoing learning and improvement within the practitioner community should be supported. The following actions are provided for consideration:

- Provision be made to present the products of this review in an online setting for ready improvement as new evidence comes to light. This would include the causal model with evidence for individual relationships, case studies, and current recommended practice.

- Current recommended practices should be written-up in more detail and placed into a separate document to assist sharing and offline use. This would include practical techniques such as:
    - how to confirm a BMAD site as opposed to other forms of eucalypt dieback,
    - how to select the most appropriate intervention for a site.
- The practitioner community should be provided with a means of submitting new and adding to existing case studies.
- An assessment should be conducted into the skills needed to properly diagnose and treat BMAD. This should inform the selection of a competency-based training program. The assessment should also inform the format of that training (i.e. online, face-to-face or combination). Consideration should be given to packaging BMAD training as a module within a broader 'eucalypt dieback' training package since diagnosis should start with the identification of the causal pathway leading to dieback.

Recommendations: What are the costs of intervention (Q4)

R4(a): An economic analysis should be conducted of the costs and benefits of actively managing woody weed regrowth post-harvest. Estimations should be made using the DPI aerial mapping as to the economic impact of BMAD on the value of harvesting areas in NSW State Forests over time.

R4(b): Costs of interventions used in the research proposed for Q3 should be monitored and published.

Recommendations: What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q5)

R5(a): A viability assessment of different interventions based on the area that needs to be treated should be built into the intervention decision support discussed in R3(k).

Recommendations: What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD? (Q6)

R6(a): Aerial mapping be completed for higher risk areas of the state. Existing mapping has shown high correlation with Bell miner density (regardless of causality) so this could be used as a guide for prioritising areas.

R6(b): Provision to be made for online submission of on-ground sites where BMAD has been identified. This will aid with ground-truthing of aerial mapping.

R6(c): Analysis be conducted on existing DPI BMAD mapping to identify the best risk indicators or preconditions for BMAD. Once this is done a BMAD risk map or site-based assessment process should be developed.

Recommendations: What are the options for systematic monitoring of BMAD status and trend across NSW? (Q7)

R7(a): Recommendations should be requested from the DPI mapping team regarding ongoing monitoring of BMAD across the state once the effectiveness of remote sensing mapping is known. This is likely to be in mid-late 2017.

1: About this review

1.1 What is bell miner associated dieback?

Bell miner associated dieback (BMAD) is a process where eucalypts enter a cycle of defoliation and regrowth, but if conditions persist, large areas of dieback and tree death can occur. While there are multiple causes of eucalypt forest dieback, this form is associated with an over-abundance of the native bell miner bird (*Manorina melanophrys*) and psyllid insects (including *Glycaspis* and *Cardiaspina* spp.).

BMAD can lead to significant ecological, economic and social impacts. It has been listed as a key threatening process under the NSW *Threatened Species Conservation Act* 1995 and is known to directly impact threatened vegetation communities (e.g. Blue Gum High Forest ecological community) by leading to a loss of habitat for native flora and fauna (OEH, 2016).

BMAD is known to exist along the eastern seaboard of Australia from south-eastern Queensland to Victoria. Its total extent is not currently known although various publications have estimated it is in the tens of thousands of hectares. It not only threatens biodiversity but it also affects the value of forestry operations, and potentially tourism and recreational industries.

1.2 Who commissioned and funded this review?

This review was commissioned by the NSW Office of Environment (OEH) on behalf of the following NSW government departments:

- Environmental Protection Authority
- Forestry Corporation NSW
- NSW Department of Industry
- Office of Environment and Heritage.

The NSW Environmental Trust funded the project.

1.3 Review project governance

The review was guided by a project steering committee with the following members:

- Jeremy Black, Director Native Vegetation Information, Office of Environment and Heritage
- Carolyn Davies, Director Conservation Programs, Office of Environment and Heritage
- Michael Hood, Director Forestry Branch, Environment Protection Authority
- Robert Quirk, Executive Director Park Operations, Office of Environment and Heritage
- Chris Slade, Senior Ecologist, Forestry Corporation of NSW
- Christine Stone, Leader Forest Science, NSW Department of Industry – Lands & Forestry
- Mike Roache, Principal Project Officer Threatened Species, Office of Environment and Heritage

1.4 Aims of the review

The most recent review of BMAD in NSW was undertaken in 2006 (Wardell-Johnson et al., 2006a). There has been a significant amount of scientific and on-ground work since that review that needs to be incorporated into the current understanding of BMAD causes and interventions.

This review addresses the following questions, which were developed by the project steering committee.

- What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD? (Q1)

- What are the options for systematic monitoring of BMAD status and trend across NSW? (Q2)
- What causative factors lead to BMAD? (Q3)
- What are the economic, social and ecological impacts of BMAD? (Q4)
- What are the most effective management interventions to control BMAD, prevent BMAD and restore healthy forest? (Q5)
- What are the costs of intervention? (Q6)
- What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q7)

The review establishes a contemporary evidence base to guide the development of future activities and investments to manage BMAD in NSW.

1.5 Review approach

The review applied a project methodology based on the *realist review* approach to maximise transparency and minimise bias. Broadly this approach includes the following key steps: (1) ask a focused question(s), (2) search for evidence, (3) appraise primary studies and extract data, (4) synthesise evidence and draw conclusions, and (5) disseminate the findings (Pawson et al., 2005). The following are important foundations of the systematic review approach taken.

- Application of a systematic method to identify evidence and assess its admissibility.
- Searches and search sources must be transparently documented.
- Clear criteria must guide the inclusion or exclusion of individual items of evidence found.
- An assessment of the potential for bias must be undertaken for individual items of evidence, and where the volume of items found allows, poorer quality evidence should be removed from the data set to avoid biasing conclusions.
- Evidence of causality is not restricted to observation of the threatening process developing; it is also important to use the results of interventions to inform the causal hypothesis.
- Where possible, synthesis products are developed to combine and assess findings from the primary evidence.

1.6 Structure of this report

This report is structured in the following parts.

Section 1: **About this review**

Section 2: **The causes and impacts of BMAD**

What causative factors lead to BMAD? (Q1)

What are the economic, social and ecological impacts of BMAD? (Q2)

Section 3: **BMAD interventions**

What are the most effective management interventions to control, prevent and restore BMAD? (Q3)

What are the costs of intervention? (Q4)

What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q5)

Section 4: **The status of BMAD in NSW**

What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD? (Q6)

What are the options for systematic monitoring of BMAD status and trend across NSW? (Q7)

Section 5: Bibliography

Appendices

Sections 2, 3, and 4 each have the following sub-sections: introduction, methodology, results and discussion, and recommendations.

1.6 Declarations

It is acknowledged that there may be a perceived conflict of interest with the inclusion of Dr Angus Carnegie in the team given he is a NSW Department of Primary Industries employee with a funding contribution from the Forestry Corporation of NSW.

Apart from the usual methodological traits of systematic reviews that manage bias, the following additional steps were taken to manage any potential conflict of interest.

- Dr Carnegie was not involved in the search for evidence items.
- Dr Carnegie was not involved in the selection of relevant items for inclusion in the evidence base.
- The BMAD state and transition model was initially developed by M. Silver then reviewed by Dr Carnegie and the Project Steering Committee
- The BMAD causal loop model was initially developed by M. Silver then reviewed by Dr Carnegie and the Project Steering Committee
- Independent experts reviewed the causal models and associated synthesis, including the critical appraisal of evidence conducted by Dr Carnegie.

2. The causes of BMAD

2.1 Introduction

As in any field, an accurate diagnosis of the issue is critical for the prescription of effective interventions. The causes of BMAD continue to be the subject of some debate in the scientific and practitioner communities, including whether BMAD is a separate diagnosable process to other forms of forest dieback.

The purpose of this review was to assess the causal evidence provided from BMAD sites, not to review dieback at all locations and of all types. This approach does not restrict a conclusion that the processes occurring at 'BMAD sites' are identical to those occurring elsewhere.

The following questions are reviewed in this section.

- **What causative factors lead to BMAD? (Q1)**
- **What are the economic, social and ecological impacts of BMAD? (Q2)**

2.2 Method

The Project Team followed the steps in Figure 1 to collate and synthesise evidence related to questions in this section of the review. The remainder of this section provides detail about each step.

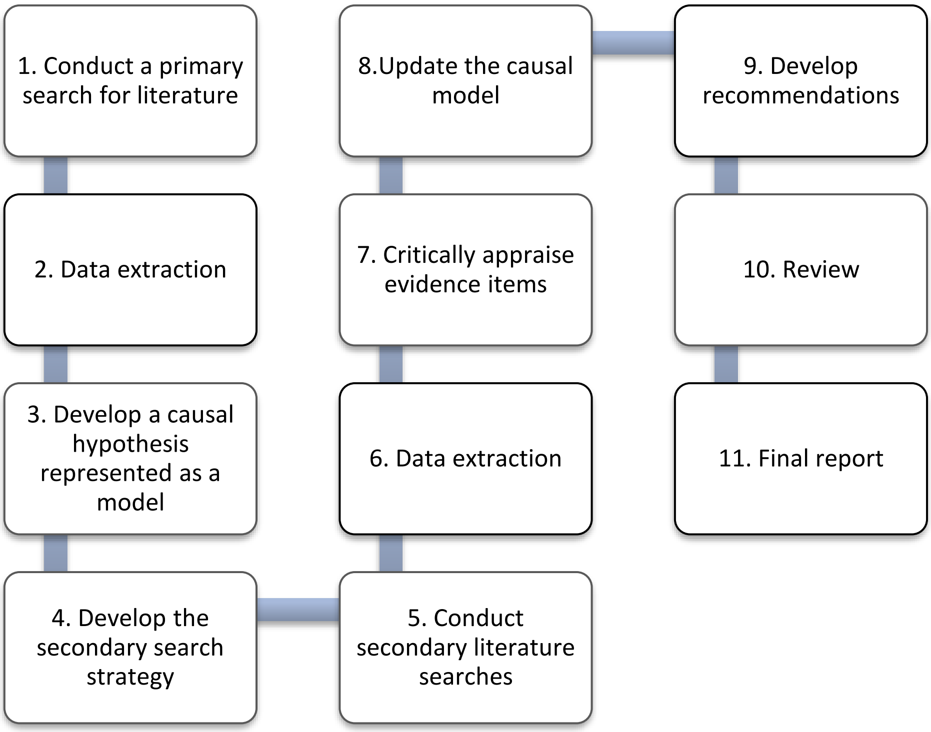

Figure 1. Steps in the method to review the evidence related to the causes of BMAD.

Step 1: Conduct a primary search for literature

As the search strategy needed to yield results related to bell miner ecology, as well as BMAD causality, extent, mapping and management interventions, the Project Team decided that the simple search strings listed in Table 1 would be necessary to ensure the identification of all relevant studies. Searches were undertaken in English and were not restricted by publication date.

Table 1. Search strings

Source	Search string	Date of search
Web of Science	“bell miner*”	21 July 2016
Trove (book type only)	“bell miner*”	23 July 2016
Google Scholar	“bell miner*”	21 July 2016

* is the Boolean search modifier for a root word, stem, or truncation search.

Bibliographic databases

The following bibliographic databases were searched for publications.

- Thomson Reuter’s (formally ISI) Web of Science™ Core Collection http://apps.webofknowledge.com/
- Trove http://trove.nla.gov.au/

Search engines

An Internet search in Google Scholar was conducted. All records were retained for screening using the inclusion/exclusion criteria.

Project Steering Committee literature

The Project Steering Committee contributed a collection of literature that they had collated.

Study inclusion criteria

After all the search results were compiled and duplicate items removed, the remaining search results were screened and included/excluded according to the following criteria:

- *Relevant location*: Study must be from Australia.
- *Relevant language*: Study must be available in English.
- *Relevant subject*: Q1: Study must be related to BMAD, including Bell miner ecology and eucalypt dieback. Note there may be causal factors or interventions that are relevant to BMAD but do not specifically mention BMAD. Q2: item must include discussion of the ecological, social, or economic effects of eucalypt dieback.
- *Relevant study design:* Q1: study must be scientifically designed and contain primary data. Books without new data, comments and opinions are excluded. Q2: this criterion did not apply to Q2.

Step 2: Data extraction

One coder conducted all data coding for the included articles and recorded the results in a Microsoft Excel spread sheet. The data categories described in Table 2 were used to record information for each article.

The study coding strategy was designed so that, wherever possible, fixed answers were selected from coded dropdown lists. Data such as publication name, volume, and page start and end were not recorded within Excel. These details can be easily interrogated using Zotero; the bibliographic software used to store each record.

Step 3: Develop a causal hypothesis represented as a model (synthesis)

A draft causal model was developed based on the extracted data. It was decided that two related models would be useful: 1) a state and transition model to define the forest dynamics, and 2) a causal model to represent processes within the ‘BMAD state’ of the state and transition model.

Table 2. List and description of meta-data variables extracted during coding.

Meta-data	Description
Title	Source article title
Author	Source article author
Date	Source article date
Investor(s)	Name
Latitude	Latitude stated within article
Longitude	Longitude cited within article
Study start year	Year the study commenced
Study end year	Year the study ceased
Causal relationship(s) studied – or relevant causal relationship	Cause and effect
Unit of analysis	Will vary based on relationship
Correlation significance	+, not significant, -
Past and present land use and management practices	Short description

Step 4: Develop the secondary search strategy

To ensure that relevant evidence was not excluded from informing causal relationships in the draft model created in Step 2, a broader search strategy was developed. An analysis of the BMAD aerial data was initially undertaken to determine whether it would be reliable to include evidence from certain vegetation types (for example could we use 'wet sclerophyll' in search phrases), however the analysis showed that this approach to developing inclusion criteria for BMAD would not be appropriate since it occurs across multiple vegetation types.

The second approach taken to determining appropriate use of evidence from non-BMAD sites was to assess each relationship in the draft causal model. The decision process in Figure 2 was used. This decision process was aimed at minimising the potential for bias, so data from non-BMAD sites was only used when necessary (due to low quantities of evidence from BMAD sites) and when it was deemed viable. The main criteria applied to determine the viability was whether the relationship was the degree of universality in the relationship. If there were large degrees of variance in the relationship and the reasons for this were not well understood, then no further searches were developed.

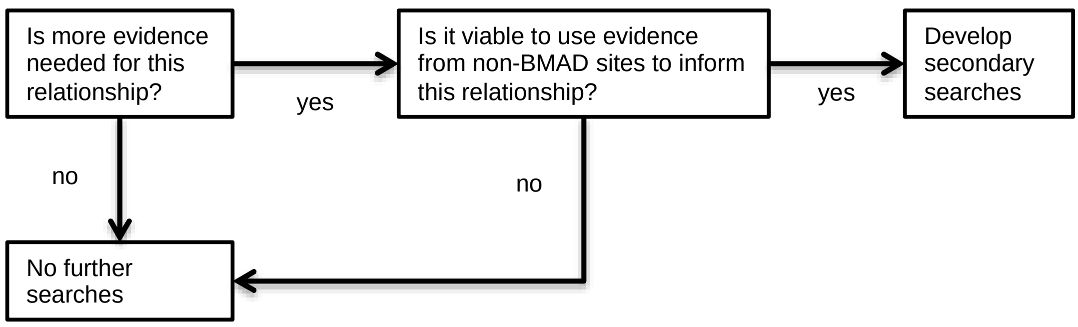

Figure 2. Decision process for determining whether to use evidence from non-BMAD sites.

Step 5: Conduct secondary literature searches

The secondary literature searches listed in Table 3 were undertaken. Inclusion criteria were applied and where items did not meet the requirements a reason was documented for exclusion.

Table 3. Secondary literature search strings.

Source	Search string	Date of search
Google Scholar	"eucalypt* AND (starch OR carbohydrate) AND defoliation"	14 December 2016
Google Scholar	"lantana AND (invasion OR coloni* OR establish*) AND eucalypt* AND australia"	13 December 2016
Google Scholar	""water stress" AND psyllids AND eucalypt* AND australia"	13 December 2016

Step 6: Data extraction (2)

The new data identified from the secondary searches was extracted according to Step 2.

Step 7: Critically appraise evidence items

Critical appraisal was undertaken for items included for Q1 but not Q2. This is because of the very low volume of evidence available for Q2. For Q1, critical appraisal was confined to those items that included measurements of a cause and effect relationship within the causal model (Figure 4), for example quantification of the relationship between the densities of understorey and the abundance of bell miners.

The framework used for critical appraisal was based on the Eco Evidence method published by Nichols et al. 2011 (see http://www.toolkit.net.au/Tools/Eco-Evidence/documentation). The framework objectively evaluates evidence within environmental science studies for bias and subjectivity.

The Eco Evidence approach was used to weight individual items of evidence, with one significant modification. The potential for bias within a study design was assessed and applied as a weighting to the Eco Evidence score. The appraiser identified the degree of the deduction (25%, 50% or 75%). This modification acknowledged that studies of the same type could vary in quality. Bias types considered included:

- **selection bias**: are individuals in the exposed and non-exposed groups identical for all-important respects except for the condition in question?
- **information bias**: what is the potential for incorrect determination of the exposure or the outcome? Sometimes called measurement or observation bias and includes consideration of whether sufficient time has been given to allow the outcome to occur as a result of the exposure/treatment.
- **confounding**: could the outcome be caused by a factor different to the exposure measured?

The data categories described in Table 4 were recorded for each critically appraised study. The types of study design and their descriptions in Table 5 are modified from Nichols et al. 2011.

Table 4. List and description of meta-data variables extracted during quality assessment.

Meta-data	Description
Study type	Refer to Table 4.
Number of independent sampling units: control	#
Number of independent sampling units: impact	#
Potential for bias rating	1 (no concerns), 0.75 (some concerns), 0.5 (significant concerns)
Justification for potential bias rating	Short description.

Table 5. Descriptions of study design types (modified from Nichols et al. 2011).

Study design type	Description
Case study observations	Casual, non-systematic observations of cases. This will focus on observed changes in the ecosystem as opposed to statements of causality that are based on opinion.
After impact only	A comparison of variable(s) from impact locations with a standard of some kind but not with control/reference location/s, and with no data before the impact compared.
Control/Reference vs. Impact - with no before data	Any case where reference/control locations are compared to impact locations without before-impact data for the impact locations.
Before vs. After - with no reference/ control data	Sampled Before and After the onset of a causal agent with no reference/control.
Gradient Response Models	An investigation of an association between the causal agent and response along a causal-agent gradient (e.g. using correlation or regressions). The data may include pristine locations through to highly disturbed locations or may have no pristine locations but have locations disturbed to different degrees. The results from gradient- response study designs will provide a dose-response gradient. Gradients may also occur through time, with sequential sampling of location/s providing the 'dose-response' relationship. The analyst is not required to distinguish between impact and reference/control locations for a gradient design. The total number of locations used in the gradient study should be recorded (note that locations are still required to be independent sampling units). For example, sampling along a longitudinal gradient at one site, is still only 1 site.
BACI/BARI	Before After Control Impact or Before After Reference Impact. 1 control/reference location, 1 impact location sampled once (may include sub-sampling within a location). Compares changes at two locations, i.e. Control/Reference and Impact locations, Before and After the impact.
BACIP	1 control location, 1 impact location sampled through time at the same times, i.e. paired measurements from control and impact locations. Sampling through time with large intervals during both the Before and After periods is used to estimate the temporal variation in the differences between control and impact locations. The temporal variation is used to assess the average difference Before and After the activity commences. The time intervals are large enough to prevent autocorrelation in these differences, and are viewed as a random sample of possible values in each period.
MBACI/MBARI	Multiple Control/Reference locations and 1 or many Impact locations. Or, multiple impact locations and 1 or many control/reference locations. Also includes replication in time.
Systematic review	A comprehensive review of evidence that includes the following methodological components: 1. A-priori protocol 2. Comprehensive use of search sources and appropriate range of phrases 3. Study inclusion/exclusion criteria 4. Assessment of study quality Qualitative and where possible quantitative synthesis of data.

Step 8: Complete the synthesis products

New data extracted from the secondary searches and the critical appraisal was used to further detail the causal model. This included the assessment of uncertainty for each relationship in the model.

The method used in Step 8 of the Eco Evidence approach (Nichols et al., 2011) was slightly modified and applied to assess causality.

The Eco Evidence approach assesses and combines assessments of the following causal criteria:

- Response
- Dose-response
- Consistency of association

The modification was:

1. There must be a 'plausible mechanism' available to describe how the cause leads to the effect for each relationship. If not, causality is deemed not to be supported and no further assessment is undertaken.

The same method of combining the causal criteria will be applied.

Outcomes	Response	Dose-Response	Consistency of Association	Conclusion
Outcome 1	H	H	H	Support for hypothesis
Outcome 2	H	L	H	Support for hypothesis
Outcome 3	L	L	H	Insufficient evidence
Outcome 4	H	H	L	Inconsistent evidence
Outcome 5	H	L	L	Inconsistent evidence
Outcome 6	L	L	L	Support for alternative hypothesis
Outcome 7	No evidence supplied	No evidence supplied	No evidence supplied	No evidence supplied

Figure. The eco-evidence method of combining assessments of causal criteria to draw a conclusion about causality for a relationship.

A text-based discussion of items relating to Q2 was compiled.

Step 9: Develop recommendations

A set of recommendations related to the review questions was developed based on the collated and assessed evidence. Recommendations related to how the evidence base could be further strengthened and how practitioners could be assisted with application of the available evidence.

Step 10: Peer review

The draft report was reviewed by the BMAD Project Steering Committee and was made available to survey respondents that indicated an interest in reviewing the draft causal model.

Step 11: Final report

Comments from the review process were assessed and relevant changes were made before delivering the final report to the BMAD Project Steering Committee.

2.3 Results and discussion

2.3.1 What causative factors lead to BMAD? (Q1)

Summary of evidence sources

Primary desktop search

The primary search yielded 984 peer-reviewed and grey literature documents that were then screened for relevant items. After removing duplicate items from the search results, items were screened by abstract and/or full text to determine if they would be included.

A total of 115 studies were judged as having met the inclusion criteria for question 1 and a further 7 studies for question 2. These studies have been cited in this review and are presented as part of an annotated bibliography in Appendix A if they include measurements of relationships.

At the writing of this report we have been unable to locate full text records for 23 of the studies, each of which cannot be excluded using title or abstract.

Secondary desktop search

The secondary searches related to causal relationships in the draft models yielded a total of 125 returns. Of these, 40 were assessed as meeting the inclusion criteria. These studies are annotated in Appendix A, and cited in the relevant causal relationships in the BMAD causal model below.

Project Steering Committee literature

The Project Steering Committee also provided a collection of 103 studies. Each of these was assessed using the inclusion criteria and a significant number were duplicates of the primary search. Any included studies are also presented in the annotated bibliography (Appendix A).

Document citations

A small number of items were identified from citations within other evidence items. These are also documented in Appendix A.

Synthesis product: BMAD state and transition model

The two synthesis products relating to review Q1 are a state and transition (S&T) model and a causal model. These two models are related in that the causal model represents one state of the S&T model, the active BMAD state (State 2).

An S&T model is designed to illustrate the different states that a single system can be in and what drives the system from one state to another (Stringham et al., 2003). The S&T model presented in Figure 3 represents a forest ecosystem that would not under normal circumstances (i.e. without human intervention) be susceptible to BMAD. It is therefore not aiming to represent native vegetation communities that may naturally be susceptible to BMAD without disturbance.

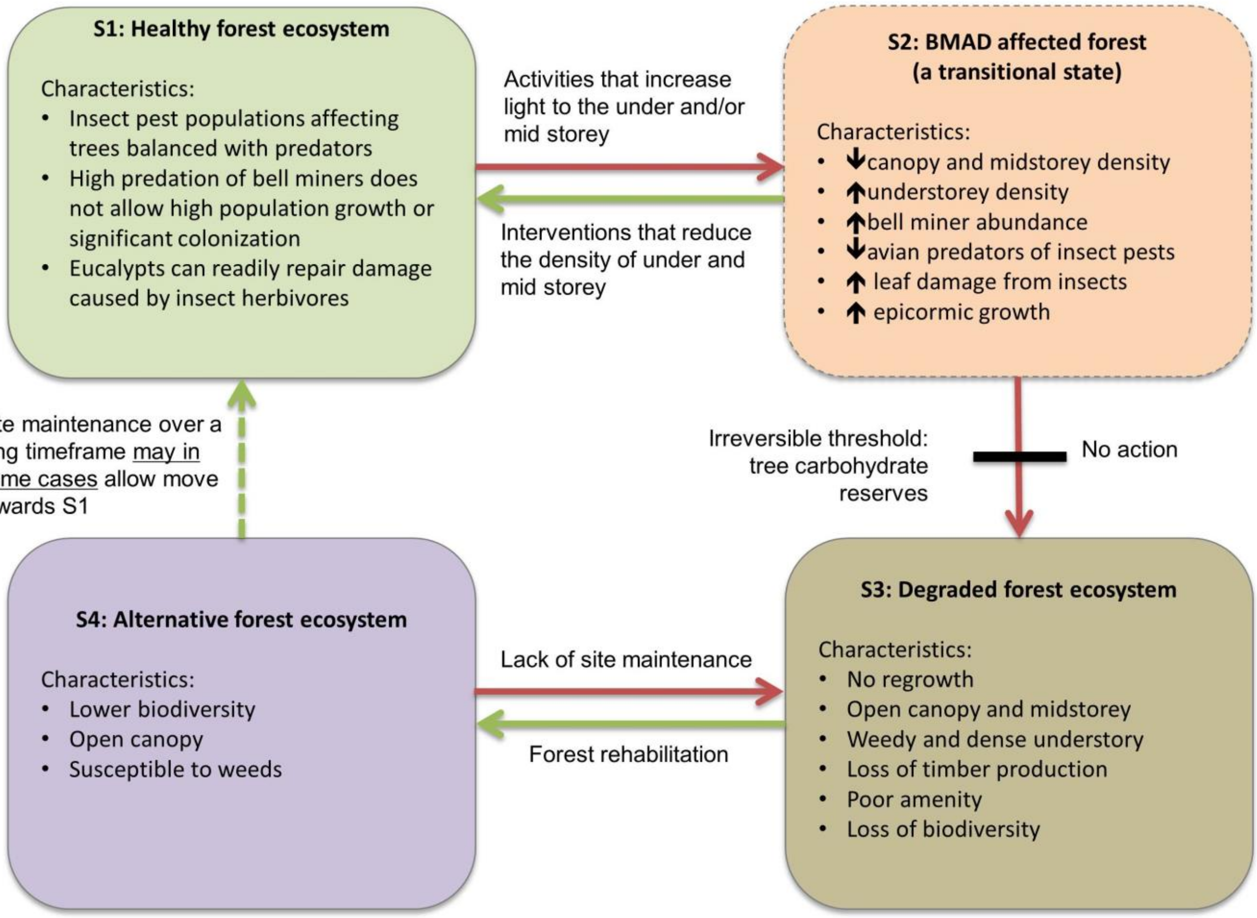

Figure 3. BMAD state and transition model.

Key points to note about the S&T model are listed below.

- The model predicts that psyllid infestations can occur in healthy forest systems, however those infestations are limited by predation of psyllids.
- The key driver of healthy ecosystems (S1) into the BMAD affected state (S2) is the increase of light to the understorey or mid-storey. This in turn leads to more dense nesting sites for Bell miner.
- S2 is a transitional state — without intervention, the system will progress to S3.
- Once the system is in S2 for a period of time, tree carbohydrate reserves will breach an irreversible threshold. This threshold provides an explanation for some cases where treatment is applied but trees do not recover.
- While there is a line from S4 to S1, it is by no means certain that a rehabilitated forest site will evolve towards S1 over time. It is likely that significant site maintenance will be required to stop S4 from moving back to S3 until a canopy is established. The pathway from S4 to S1 may involve a change in forest species composition.

Synthesis product: BMAD causal model representing State 2 (S2)

Figure 4 illustrates the complexity of the causal pathways involved in BMAD using a causal relationship model. This type of model aims to represent detailed causal pathways related to an issue. The remainder of this section analyses the evidence against each relationship.

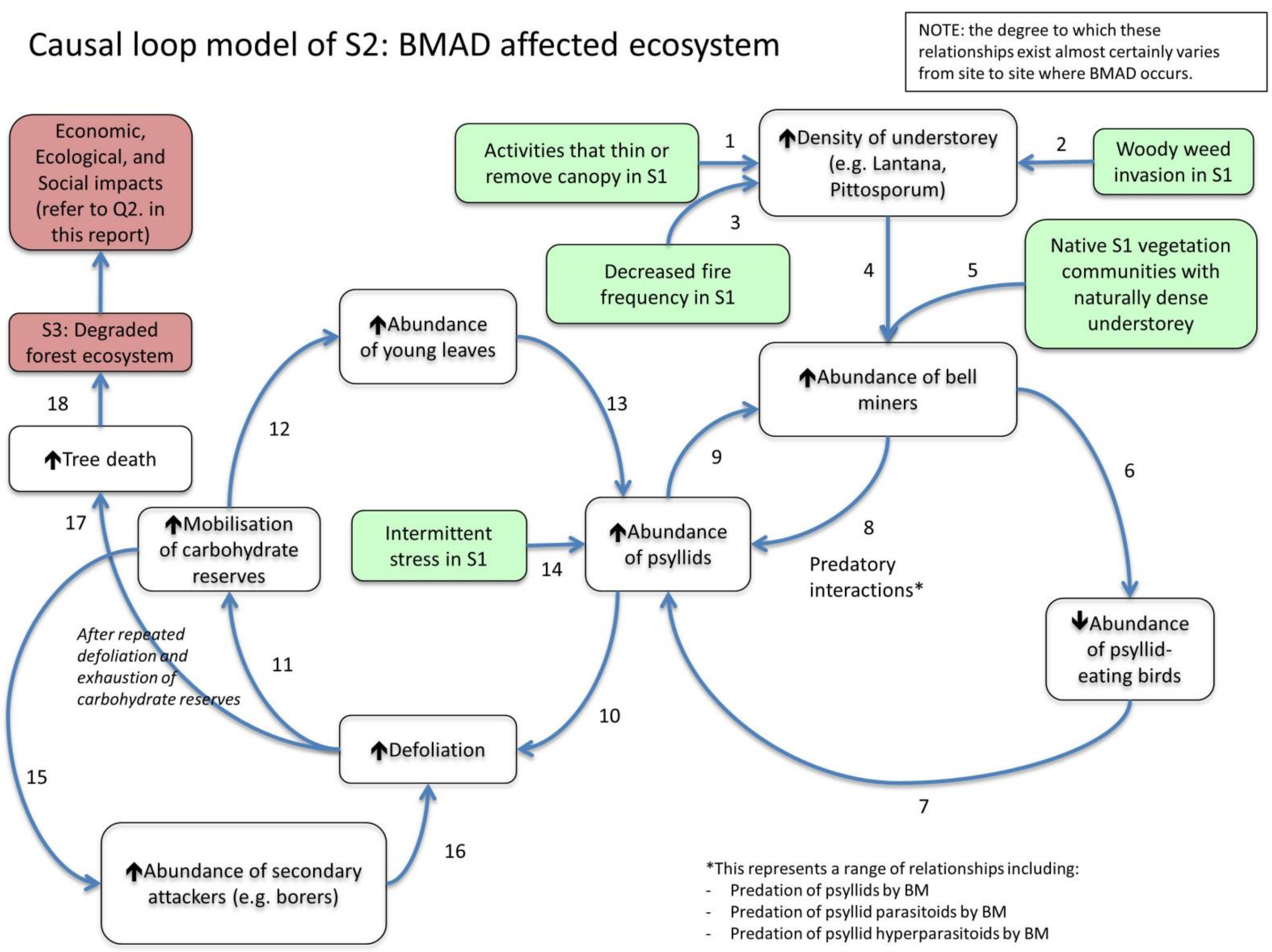

Figure 4. BMAD causal model

RELATIONSHIP 1.

Activities that thin or remove canopy ➔ [increases] Density of understorey

Plausible mechanism explaining the relationship

Activities that reduce the density of overstorey canopy, or produce gaps in the overstorey, result in increased light availability and reduced competition for space and other resources resulting in an increase in density of understorey plants, such as lantana. Experimental manipulation to mimic disturbance by fire and cattle to reduce overstorey canopy density significantly increased survival, growth (biomass) and site occupation of lantana in dry rainforest-open forest ecotones in northern Queensland (Duggin and Gentle,1998; Gentle and Duggin,1997). The single greatest factor in increasing understorey density was the increase in light availability to the forest floor, with increasing biomass removal resulting in greater light availability and increased lantana invasion success. Fensham *et al*. (1994) reported that dry rainforest sites with heavy infestations of lantana (>5000 plants per ha) had significantly thinner overstorey canopies compared to sites with light infestations of lantana (<1000 plants per ha). However, although not significant, this trend was reversed for savanna woodland sites, with the heavily infested lantana sites having denser canopies than the lightly infested sites. Reduction of overstorey canopy cover by tree removal (harvesting) in a mature *E. grandis* plantation in northern NSW significantly promoted lantana cover in the understorey (Cummings et al., 2007). Tree removal and follow-up weed control (primarily lantana) also promoted regeneration of native shrubs and trees in the understorey; however, with greater understorey density under a denser overstorey canopy. Moore (1972) found that clear-felling greatly increased the growth rate of regeneration compared to areas with no tree removal. Somerville et al. (2011) observed increased lantana growth under sparse canopies: in areas with low density of lantana and high overstorey canopy density, lantana is slow to recover from physical and chemical control, but in heavily infested area in degraded forest (sparse canopies), re-treatments of lantana are necessary until the native mid-storey develops to shade-out lantana.

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Cummings et al., 2007)	4	Yes	Yes	Yes
(Duggin and Gentle, 1998)	3	Yes	Yes	Yes
(Fensham et al., 1994)	4	Yes	Yes	Yes
(Gentle and Duggin, 1997)	4	Yes	Yes	Yes
(Somerville et al., 2011)	2	Yes	No	Yes
(Moore, 1972)	6	Yes	Yes	Yes
TOTAL		23	21	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 2.

Woody weed invasion ➔ [increases] Density of understorey

Plausible mechanism explaining the relationship

Numerous studies have shown that woody weed invasion, especially lantana, leads to an increase in density of the understorey, often to the detriment of native understorey and mid-storey tree species. Canopy thinning or gaps provide ideal conditions for lantana (primarily increased light), which tends to subsequently dominate the site (Duggin and Gentle,1998; Gentle and Duggin,1997). Lantana can take better advantage of increased resources (nutrients) following disturbance, thus accumulating more biomass and further suppressing native shrub species (Gentle and Duggin, 1998). Gooden et al. (2009b) described a change in vegetation structure whereby increasing invasion of lantana results in a reduction in native species richness, especially of shrub and tree species, leading to a change from tall open forest to an understorey dominated by lantana. Fensham et al. (1994) described areas long-invaded by lantana as having a dense understorey consisting of >5000 lantana plants per hectare, compared to <1000 plants per hectare in newly invaded areas. Debuse and Lewis (2014) showed that lack of fire over a long period can significantly increase the density of lantana, while frequent fire, over the long-term, can actually reduce lantana density. Rose (1997) investigated the native understorey tree *Pittosporum undulatum* in urban fringe forests in Sydney and found that basal area and density increased with increasing age of invasion, both temporally and spatially. Invasion by woody weeds, such as lantana, affects native vegetation regeneration, ultimately affecting species diversity, including of understorey, mid-storey and canopy species, thus perpetuating a dense understorey (Gooden et al. 2009a, b; Cummings et al. 2007).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Debuse and Lewis, 2014)	6	Yes	Yes	Yes
(Duggin and Gentle, 1998)	3	Yes	Yes	Yes
(Fensham et al., 1994)	3	Yes	Yes	Yes
(Gentle and Duggin, 1997)	4	Yes	Yes	Yes
(Gooden et al., 2009a)	5	Yes	Yes	Yes
(Gooden et al., 2009b)	9	Yes	Yes	Yes
(Rose, 1997)	8	Yes	Yes	Yes
TOTAL		38	39	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 3.

Decreased fire frequency ➔ [increases] Density of understorey

Plausible mechanism explaining the relationship

Following is a summary of information provided by Andy Baker, Liz Tasker and Penny Watson after the review-phase of the project (step 10 of the method). The references cited have been reviewed, but were not included in the critical appraisal. Note this is not a systematic review of this relationship.

There is abundant published research from eucalypt forests of eastern Australian coasts and ranges that show that low or reduced fire frequencies (or the absence of fire) are major determinant of increased understorey density, increased shrub cover and the invasion of rainforest understorey. Reduced fire frequency allows the recruitment of fire-sensitive trees, shrubs and vines (e.g. *Lantana camara, Cissus antarctica, Cissus hypoglauca, Pittosporum undulatum*) into the understorey of eucalypt forests, which in the continued absence of fire, grow to form a dense understorey that provides more dense nesting sites for Bell miners. The profound influence of fire on vegetation structure is well researched and understood. The development of a dense understorey of fire-sensitive plants following fire exclusion is a global phenomenon and widely reported in higher rainfall regions (>600 mm/yr.) in coastal eastern and northern Australia (e.g. (Brook and Bowman, 2006; Lewis et al., 2012; Rose and Fairweather, 1997; P. Stanton et al., 2014). The phenomenon has been demonstrated in experimental manipulations of fire frequency (Lewis et al., 2012)) site-based opportunistic fire exclusion experiments (Fensham and Butler, 2004; Rose, 1997) and numerous landscape scale experiments mapping rain forest understorey expansion into eucalypt forest from chronosequences of aerial photographs (Harrington and Sanderson, 1994; Rose and Fairweather, 1997; Peter Stanton et al., 2014).

In the case of *Lantana camara,* long-term fire exclusion was found to increase total plant density (Debuse and Lewis, 2014), and the density of Lantana in the 0.6–3 m height class, which is within the desired range for Bell miner nesting. While it may be unrealistic to apply fire at frequencies that eliminate Lantana from a site, the study of Debuse and Lewis (2014) showed that frequent fire can maintain Lantana below the height referred for Bell miner nesting. Burning reduces cover of Lantana, and keeps plants in a reproductively immature state for longer (Russell and Roberts, 1996).

Stone et al. (2008) found bell miners were negatively correlated with fire frequency and positively correlated with a dense understorey including *Lantana camara* and/or *Cissus antarctica* or *C. hypoglauca.*

Conversely, a high frequency of low-intensity planned fire (2-5 years approx.) is associated with an open grassy understorey and reduced shrub understorey cover (Birk and Bridges, 1989; Henderson and Keith, 2002; Tasker and Bradstock, 2006). Frequent fire kills obligate seeding shrubs before they have time to produce seed and survive the next fire and favours herbaceous fire-tolerant plants such as grasses (Morrison, 2002; Penman et al., 2008). Thus, frequent fire inhibits shrubs and promotes grasses (Birk and Bridges, 1989).

Low frequency fire is widespread throughout some regions affected by BMAD, affecting >60% of all fire-dependent vegetation, and comprising >99% of all areas affected by inappropriate fire frequency (Baker and Catterall, 2015). In the productive landscapes of north-eastern NSW and south-eastern QLD, where BMAD is prominent, a dense mid-storey may form in forests where fire interval exceeds 10 years (Watson, 2006).

The four main understorey species identified as nesting habitat for Bell miners (e.g. *Lantana camara, Cissus antarctica, C. hypoglauca* and *Pittosporum undulatum*; [Hastings, 2012; Lambert et al., 2016; Stone et al., 2008]) are fire-sensitive, and fire frequency is a primary determinant of their distribution in the landscape and prominence in the understorey (A. Baker, pers. comm.). As outlined above, Lantana density, particularly at the preferred nesting height for Bell Miners, is negatively correlated with fire frequency (Debuse and Lewis, 2014). No direct link between BMAD and Lantana (specifically) has been established (Wardell-Johnson et al., 2006b), and other native 'woody weeds' appear equally important, with Stone et al. (1995) concluding that Bell miners appeared to use a dense mid-storey for nesting sites irrespective of plant species composition. This is strongly supported by frequent reports of BMAD in regions where Lantana does not occur (Clarke and Schedvin, 1999; Hastings, 2012), and where Bell miner colonies persist after Lantana removal if a dense understorey of rainforest plants remain (Lambert et al., 2016).

Native 'woody weeds' identified as being equally important determinants of Bell miner activity (e.g. *Cissus antarctica, C. hypoglauca* and *Pittosporum undulatum*; [Hastings, 2012; Lambert et al., 2016; Stone et al., 2008]) are all limited to vegetation types characterized by infrequent fire. Specifically, Lewis et al. (2012) found that *Cissus hypoglauca* was strongly associated with unburnt treatments, while the spread of *Pittosporum undulatum* into open forests has been attributed to decreased fire frequency (Rose, 1997; Rose and Fairweather, 1997). For additional rainforest mid-storey species commonly occurring in BMAD affected forests (e.g. *Acacia irrorata, Polyscias elegans, Alphitonia excelsa, Cupaniopsis parvifolia, Guioa semiglauca, Mallotus philippensis, Drypetes deplanchei*) the 'Decrease Fire Frequency' relationship is likely to also apply (A. Baker, pers. comm.).

Assessment of support for hypothesis

Please note that this relationship is not based on a full systematic review of the evidence base. Therefore no formal assessment of causality was undertaken.

RELATIONSHIP 4.

Increased density of understorey ➔ [increases] Abundance of Bell miners

Plausible mechanism explaining the relationship

A dense understorey, either of exotics (e.g. lantana) or natives, is said to be the preferred habitat of Bell miners for nesting as it is assumed such habitat "facilitates cooperative defence of their territory from predators and competitors (Stone et al., 2008). Several studies have provided anecdotal evidence to support this (Clarke and Heathcote, 1990; McDonald et al., 2002). Clarke (1988) and Smith and Robertson (1978) observed the majority of nests in dense understorey of native and exotic shrubs below 3 m. Clarke and Heathcote (1990) reported very high mortality rates for nestlings (70%), with predation the major cause of mortality (Clarke, 1988). Other studies have investigated this in more detail, with results also supporting this relationship. Assessments of characteristics at dieback sites across eight Districts in central and northern NSW revealed 93% of plots had Bell miners and 90% a medium to dense understorey (Stone et al., 1995). There was a very strong association between dense understorey and the presence of Bell miners in dieback sites, but no indication of a density-dependant relationship. In a separate study, in Richmond Range State Forest, northern NSW, Stone (2005) identified that eucalypt stands susceptible to Bell miner colonisation generally support a dense shrubby understorey. StClair (2010) trialled various intervention treatments—logging, lantana removal and fire—to try and regenerate declining eucalypt forest in Mt Lindesay State Forest, northern NSW—forest infested with psyllids and abundant Bell miners. There was a significant correlation between lantana density and Bell miner abundance across the sites; as lantana cover increased so did Bell miner abundance. Stone et al. (2008) conducted detailed assessments of forest and site attributes, including canopy health and stand structure, in 130 plots on the central coast of NSW. Bell miners were present in 37 plots, and there was a significant association between Bell miners and a dense lower mid-storey. Somerville et al. (2011) observed large persistent colonies of Bell miners associated with dense understorey of lantana in degraded forest in northern NSW. The removal of lantana resulted in the Bell miners relocating and being absent from three sites, but persisting in two sites that had dense lantana in adjacent forest. Lambert et al. (2016) observed Bell miners associated with dense understorey of either exotic lantana or native vegetation.

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clarke, 1988)	2	Yes	Yes	Yes
(Clarke and Heathcote, 1990)	2	Yes	No	Yes
(Lambert et al., 2016)	6	Yes	Yes	Yes
(McDonald et al., 2002)	4	Yes	No	Yes
(Smith and Robertson, 1978)	2	Yes	Yes	Yes
(Somerville et al., 2011)	2	Yes	Yes	Yes
(StClair, 2010)	2 (4x0.5)	Yes	Yes	

(Stone, 2005)	4	Yes	Yes	Yes
(Stone et al., 1995)	4	Yes	No	Yes
(Stone et al., 2008)	4	Yes	Yes	Yes
TOTAL		32	22	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 5.

Native S1 vegetation communities with naturally dense understorey ➔ [increases] Abundance of Bell miners

Plausible mechanism explaining the relationship

A dense understorey is said to be the preferred habitat of Bell miners for nesting as it is assumed such habitat "facilitates cooperative defence of their territory from predators and competitors (Stone et al., 2008). Clarke (1988) and Smith and Robertson (1978) observed the majority of nests in dense understorey of native and exotic shrubs below 3 m; both studies in areas known to have BMAD.

Assessment of support for hypothesis

Conclusions: *Insufficient evidence to support the hypothesis*

Note: This relationship is hypothesised based on the causal process identified. There have also been anecdotal reports of BMAD in native forests with dense understorey however these cannot be included as supporting evidence due to the inclusion criteria for evidence related to this review question.

RELATIONSHIP 6.

Increased abundance of Bell miners ➔ [decreases] Abundance of psyllid-eating birds

Plausible mechanism explaining the relationship

Numerous studies have shown that Bell miners apply interspecific aggression via mobbing behaviour to exclude other avian species from their colony territory. Smith and Robertson (1978) monitored Bell miner activity over a 2-year period in Bundoora, Victoria. Of 30 other avian species that entered areas occupied by Bell miners, 26 were attacked and expelled; all harassed species were those that occupy the same niche as Bell miners. Clarke (1984) later monitored the same Bell miner community at Bundoora, and observed that three other avian species occurred at the site, but that the majority of other avian species were actively excluded. A group of Noisy Miners invaded and displaced the Bell miners in one section of the Bundoora community, then inexplicably left. Within two weeks 15 other avian species colonised the site — but not the Bell miners — which was initially dominated by species that inhabit the same niche and directly compete for food (lerp psyllids) with Bell miners. Poiani et al. (1990) monitored bird abundance over seven years at a site in Healesville, Victoria, where Bell miners have been invading. They reported a (non-significant) negative correlation between Bell miner abundance and abundance of competitor honeyeaters, with non-competitors seemingly unaffected by the invading Bell miners. In forest at Yellingbo State nature Reserve, Victoria, Pearce et al. (1995) monitored bird abundance following the removal of Bell miners from some of the sites. Helmeted Honeyeaters immediately visited sites where Bell miners had been culled, establishing colonies at these sites within one year. Clarke and Fitzgerald (1994) observed that other avian species were almost totally excluded from areas defended by Bell miners over a 4-year period in Bundoora, Victoria. Following a Bell miner cull, Clarke and Schedvin (1999) observed a significant influx of other avian species, especially those that fed on psyllids. Prior to the cull, this site had lower avian diversity than a “control” site with no Bell miners. Dare et al. (2007) observed that even at low densities, Bell miners making their characteristic “tink” calls exclude other avian species, thus reducing avian diversity. Kemmerer et al. (2008) showed that when Bell miners are present in forests with dense understorey species, they dominate the avian community, with a negative linear relationship between Bell miner density and species richness and abundance. Removal of Bell miner habitat (dense lantana understorey) resulted in Bell miners vacating sites, being replaced by other bird species (Somerville et al., 2011). The reduction in avian diversity is primarily a result of Bell miners excluding other species that inhabit the same niche, or feeding guild, as them, including psyllid-eating birds such as spotted pardalotes, white-naped honeyeaters and crimson rosellas (Clarke, 1984; Clarke and Schedvin, 1999; Leseberg et al., 2014; Smith and Robertson, 1978; Clarke & Fitz-Gerald 1994; Loyn et al. 1983).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clarke, 1984)	2	Yes	Yes	Yes
(Clarke and Fitzgerald, 1994)	2	Yes	Yes	yes
(Clarke and Schedvin, 1999)	6	Yes	Yes	Yes
(Dare et al., 2007)	2 (4x0.5)	No	No	No

(Kemmerer et al., 2008)	3	Yes	Yes	Yes
(Leseberg et al., 2014)	9	Yes	Yes	Yes
(Pearce et al., 1995)	6	Yes	Yes	Yes
(Poiani et al., 1990)	4	Yes	Yes	yes
(Smith and Robertson, 1978)	2	Yes	Yes	Yes
(Somerville et al., 2011)	4	Yes	Yes	Yes
(Stewart, 1990)	4	Yes	Yes	Yes
TOTAL		42	42	2
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 7.

Decreased abundance of psyllid-eating birds ➔ [increases] Abundance of psyllids

Plausible mechanism explaining the relationship

A high proportion of the avian species that are excluded from Bell miner sites, such as spotted pardalotes, white-naped honeyeaters and crimson rosellas, predate on psyllids (Clarke, 1984; Clarke and Schedvin, 1999; Leseberg et al., 2014; Smith and Robertson, 1978; Clarke & Fitz-Gerald 1994). Thus, if these birds are excluded, this is likely to lower overall psyllid predation. Loyn et al. (1983) removed Bell miners from psyllid and dieback affected forest to monitor the effect on avian diversity, psyllid numbers and tree health. The site was re-invaded by insectivorous birds that fed on psyllids at a far greater rate than the previous Bell miners, which ultimately "controlled" the psyllid outbreak. The "psyllid consumption" rate of other avian species was almost 2.5 times greater than of the previous Bell miner population. Clarke and Schedvin (1999) also removed bell miners from a psyllid and dieback affected forest and observed an immediate influx of other avian species and a reduction in psyllids. When bell miners later recolonised the site, with a corresponding reduction in other avian species, psyllid numbers returned to high numbers. Dare et al. (2007) monitored avian abundance and psyllid abundance in a forest recently invaded by Bell miners. The arrival of Bell miners did not result in a significant increase in overall psyllid abundance. However, very few Bell miners actually colonised the site, confounding the study. Note that the main insects involved in this relationship are species of psyllids, but that Bell miners — and other insectivorous birds — also feed on a wide range of other insects, including spiders, parasitic wasps, predatory insects, and herbivorous insects (e.g., Lambert et al., 2014; Nageli et al., 2016; Stone, 2005).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis.*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clarke and Schedvin, 1999)	7	Yes	Yes	Yes
(Dare et al., 2007)	2 (4x0.5)	No	No	No
(Loyn, 1987)	6	Yes	Yes	Yes
(Loyn et al., 1983)	6	Yes	Yes	Yes
TOTAL		19	19	2
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 8.

Increased abundance of Bell miners ➔ [increases] Abundance of psyllids

Plausible mechanism explaining the relationship

Several studies have reported an observed increase in psyllid numbers in areas supporting high numbers of Bell miners (Moore, 1962; Somerville et al., 2011; Stone and Simpson, 2006; Ward and Neumann, 1982). Removal of Bell miners from psyllid-infested forests has resulted in an influx of other avian species and a subsequent decrease in psyllids (Clarke and Schedvin, 1999; Loyn et al., 1983). Bell miners are cooperative breeders that live in small discrete colonies and aggressively defend their territory from interspecific intruders (Clarke 1988, Smith and Robertson 1978). They are insectivorous, with psyllids recognised as a primary food sources (Campbell and Moore, 1957; Poiani, 1997; Wilson, 1909). The main avian species excluded by Bell miners are also psyllid-feeders, such as spotted pardalotes, white-naped honeyeaters and crimson rosellas (Clarke, 1984; Clarke and Schedvin, 1999; Leseberg et al., 2014; Smith and Robertson, 1978; Clarke & Fitz-Gerald 1994; Loyn et al. 1983). Bell miners consume less psyllids compared to a suite of other avian insectivores (Loyn et al., 1983). Furthermore, Bell miners are said to “farm” psyllids, with evidence they often only feed on lerps — and not the underlying nymph — thus allowing the psyllid population to expand (Haythorpe and McDonald, 2010; Loyn, 1987). Steinbauer et al. (2015) observed a positive relationship between Bell miners and abundance of psyllids (more psyllids in Bell miner plots), but the effect was not universal. Steinbauer et al. (2015) also observed a positive relationship between psyllids and parasitic *Psyllaephagus* species, but no relationship with corresponding parasitism, likely due to high levels of hyperparasitism. Dare et al. (2007) observed the aggressive behaviour of Bell miners, but did not observe a corresponding decrease in psyllid abundance, likely due ineffective Bell miner density to “control” the psyllid population. Lambert et al. (2014) observed a greater abundance of insects (including psyllids) in bell miner sites (n=181) compared to non-Bell miner sites (n=67), but the difference was not significant.

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis.*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clarke and Schedvin, 1999)	6	Yes	Yes	Yes
(Dare et al., 2007)	2 (4x0.5)	No	No	No
(Lambert et al., 2014)	7	No	No	No
(Loyn et al., 1983)	6	Yes	Yes	Yes
(Moore, 1962)	4	Yes	Yes	Yes
(Somerville et al., 2011)	2	Yes	No	Yes
(Steinbauer et al., 2015)	8	Yes	Yes	Yes
(Stone and Simpson, 2006)	4	Yes	No	Yes

(Ward and Neumann, 1982)	1	Yes	Yes	Yes
TOTAL		31	25	9
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 9.

Increased abundance of psyllids ➔ [increases] Abundance of Bell miners

Plausible mechanism explaining the relationship

Numerous studies have shown the link between high numbers of psyllids and Bell miner abundance, with Bell miners observed at sites with high numbers of psyllids (Moore, 1962; Somerville et al., 2011; Stone and Simpson, 2006; Ward and Neumann, 1982; Steinbauer et al., 2015; Loyn et al. 1983). Psyllids are a primary food source for Bell miners, often consisting of over half of their diet (Campbell and Moore, 1957; Poiani, 1997; Wilson, 1909). Few studies, though, have actually tried to determine whether the increase in psyllids lead to an increase in bell miners, or visa versa. Clarke and Schedvin (1999) observed that bell miners were capable of recolonising a site before psyllid numbers had risen substantially, and only after bell miners gained control of the site did psyllid numbers increase. Lambert et al. (2014) and Dare et al. (2007) did not find a significant relationship between psyllid numbers and bell miners. Note that the main insects involved in this relationship are species of psyllids, but that Bell miners — and other insectivorous birds — also feed on a wide range of other insects, including spiders, parasitic wasps, predatory insects, and herbivorous insects (e.g., Lambert et al., 2014; Nageli et al., 2016; Stone, 2005).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clarke and Schedvin, 1999)	6	No	No	No
(Dare et al., 2007)	2 (4x0.5)	No	No	No
(Lambert et al., 2014)	7	No	No	No
(Loyn et al., 1983)	6	Yes	Yes	Yes
(Moore, 1962)	4	Yes	Yes	Yes
(Somerville et al., 2011)	2	Yes	No	Yes
(Steinbauer et al., 2015)	8	Yes	Yes	Yes
(Stone and Simpson, 2006)	4	Yes	No	Yes
(Ward and Neumann, 1982)	1	Yes	Yes	Yes
TOTAL		25	19	6
LEVEL		HIGH	LOW	HIGH

RELATIONSHIP 10.

Increased abundance of psyllids ➔ [increases] Defoliation

Plausible mechanism explaining the relationship

Numerous studies have shown a clear link between psyllid attack and defoliation (Froggatt 1923; Elliott et al. 1998). Psyllids damage leaves via their sap-sucking, causing discolouration and/or necrosis, which leads to premature defoliation. Numerous studies have observed psyllids causing defoliation at BMAD sites. Moore (1962) observed that eucalypt foliage severely attacked by *Glycaspis* spp. gradually becomes reddish-purple, the colour deepening over winter, before prematurely shedding. Stone et al. (1995) noted that psyllid-infested foliage is shed during the new flush period in spring. Ward and Neumann (1982) reported that *Glycaspis* psyllids caused premature defoliation of dieback-affected trees in Victoria. Steinbauer et al., (2015) observed discolouration and defoliation associated with *Cardiaspina* and *Creiis,* although not by *Glycaspis.* Loyn et al. (1983) described forests with defoliation and dieback attributed to psyllids.

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Loyn et al., 1983)	6	Yes	No	Yes
(Moore, 1962)	4	Yes	Yes	Yes
(Steinbauer et al., 2015)	8	Yes	Yes	Yes
(Stone et al., 1995)	4	Yes	Yes	Yes
(Ward and Neumann, 1982)	1	Yes	Yes	Yes
TOTAL		23	17	0
LEVEL		HIGH	LOW	HIGH

RELATIONSHIP 11.

Increased defoliation ➔ [increases] Mobilisation of carbohydrate reserves

Plausible mechanism explaining the relationship

When biotic or abiotic agents defoliate trees, they utilise carbohydrates — via ongoing photosynthesis or from storage organs — to replace foliage. If trees are repeatedly severely defoliated, such that photosynthesis is hindered (or ceases) due to lack of photosynthetic tissues (leaves), then carbohydrate stores can be depleted during crown replacement and ultimately result in dieback and death (Landsberg and Wylie, 1983). Severe defoliation of planted eucalypt saplings (via pruning) and native trees (via phasmatids) resulted in a significant reduction of soluble and stored carbohydrates compared to non-defoliated (healthy) trees (Old et al., 1990). This persisted for up to 12 months, suggesting a chronic depletion of the tree's energy reserves. Multiple artificial defoliation events of *E. marginata* in WA resulted in significant growth reductions, with a linear function between defoliation severity and growth loss (Abbott et al., 1993). The authors proposed that defoliation affected the production of carbohydrates via loss of photosynthetic ability, and depleted reserves due to reallocation of carbohydrates to produce new crown. Variation in lignotuber size, and consequent carbohydrate storage, of *E. obliqua* revealed that provenances with larger lignotubers had greater pools of carbohydrate reserves to replenish flush following artificial clipping (Walters et al., 2005), implying better survival of such provenances following multiple defoliation events due to fire or grazing. Comparison of forest trees revealed that starch levels are severely depleted following defoliation (artificial, fire or insect) and subsequent crown replacement, but are replaced by the subsequent photosynthesis of the new crown (Bamber and Humphreys, 1965). However, repeated severe defoliation events can totally deplete starch reserves, due to lack of replacement from photosynthetic organs, leading to tree mortality. Some species, however, are able to effectively reallocate carbohydrate reserves and recover from defoliation events, unless under limited water and nutrients (Eyles et al., 2009).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Abbott et al., 1993)	6	Yes	Yes	Yes
(Bamber and Humphreys, 1965)	8	Yes	Yes	Yes
(Eyles et al., 2009)	4	Yes	Yes	Yes
(Landsberg and Wylie, 1983)	8	Yes	Yes	Yes
(Old et al., 1990)	7	Yes	Yes	Yes
(Walters et al., 2005)	3	Yes	Yes	Yes
TOTAL		36	36	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 12.

Increased mobilisation of carbohydrate reserves ➔ [increase] Abundance of young leaves

Plausible mechanism explaining the relationship

Numerous studies have measured the mobilisation of stored carbohydrates to replace foliage following defoliation events (Walters et al. 2005; Bamber and Humphreys 1965; Eyles et al. 2009). This phenomenon has been used to explain crown replacement, or epicormic growth, following defoliation by insects, fire, or artificial pruning (Landsberg & Wylie 1983; Old et al. 1990; Abbott et al. 1993). Defoliation interferes with the production of carbohydrates via photosynthesis, so trees must mobilise carbohydrate reserves (e.g. from roots) to produce new flush, i.e. young leaves. Numerous studies have reported this mechanism through field or glasshouse manipulation trials (Abbott et al., 1993; Bamber and Humphreys, 1965; Eyles et al., 2009; Landsberg and Wylie, 1983; Walters et al., 2005).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis.*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Abbott et al., 1993)	6	Yes	Yes	Yes
(Bamber and Humphreys, 1965)	8	Yes	Yes	Yes
(Eyles et al., 2009)	4	Yes	Yes	Yes
(Landsberg and Wylie, 1983)	8	Yes	Yes	Yes
(Walters et al., 2005)	3	Yes	Yes	Yes
TOTAL		29	29	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 13.

Increased abundance of young leaves ➔ [increase] Abundance of psyllids

Plausible mechanism explaining the relationship

Clark and Dallwitz (1974) determined that the favourableness of *E. blakelyi* leaves as a source of food was the principal influence affecting *Glycaspis* spp. abundance; young leaves (4–8 weeks old) were more favourable than mature leaves, with old leaves not favourable at all. Similarly, younger leaves were more favourable for both *Spondyliaspis* and *Creiis* psyllids. Landsberg (1990) and Landsberg & Wyie (1983) reported that young, regrowth leaves are nutritionally superior than mature leaves they replace, and support higher insect populations (mainly herbivorous insects, in this case). Marsh and Adams (1995) also reported that young immature flush (epicormics) following defoliation events are rich in nitrogen and nitrogenous solutes, and that this increased the abundance of herbivorous insects. Landsberg (1988) observed greater defoliation by of young leaves compared to mature leaves, although much of the damage was by herbivorous insects.

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Clark and Dallwitz, 1974)	1	Yes	Yes	Yes
(Landsberg, 1990b)	4	Yes	Yes	Yes
(Landsberg and Wylie, 1983)	8	Yes	Yes	Yes
(Marsh and Adams, 1995)	4	Yes	Yes	Yes
(Landsberg, 1988)	7	Yes	Yes	Yes
TOTAL		24	24	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 14.

Intermittent stress in S1 ➔ [increase] Abundance of psyllids

Plausible mechanism explaining the relationship

Plant stress results in increased concentrations of nitrogen in the phloem, which benefits sap-sucking insects (Huberty and Denno, 2004). Conversely, the resultant reduction in turgor from drought stress may impede psyllid feeding due to reduced turgor. Intermittent water stress, therefore, appears to benefit sap-suckers as opposed to continuous water stress. Sap-suckers benefit from the initial increase in soluble nitrogen following water stress, but continued water stress reduces turgor, thus limiting ongoing access to nitrogen. Intermittent water stress results in a return of turgor allowing access to elevated nitrogen, and sap-suckers to benefit. Marsh and Adams (1995) found that water stress increased the concentration of nitrogen in foliage. Epicormic growth on mature trees was also high in nitrogen, with the growth of epicormic flush believed to be a result of drought or physiological stress, resulting in insect outbreaks. Stone and Bacon (1994) observed increased insect herbivory in water stressed trees, but this was related to reduced leaf size, not nitrogen content; they saw no increase in nitrogen content of leaves in drought stressed trees. Young eucalypts were subject to different water and fertiliser regimes in California and the effects on *Glycaspis* monitored (Paine and Hanlon, 2010). Trees grown under low moisture conditions resulted in a greater density of psyllids compared to trees grown under high moisture conditions. Trees under low water and high fertiliser conditions supported the greatest number of psyllids.

Moore (1962) observed egg laying preferences of *Glycaspis* along main veins indicative of a requirement for strong sap flow; *Glycaspis* species are phloem feeders (Woodburn & Lewis 1973, cited by Stone & Simpson 2006). Clark and Dallwitz (1974) determined that soil moisture and leaf age (young) were the main factors affecting the abundance of *Glycaspis.* Moore (1962) concluded that “moist conditions favour survival and increase populations of *Glycaspis*”, and that poor drainage on low quality sites during years of above average rainfall was an important factor in psyllid outbreaks. However, later observations revealed continued severe psyllid damage after wet, dry and normal years of rainfall, and this change from excessive rainfall to drought is likely to have stressed trees (Moore, 1972).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Huberty and Denno, 2004)	9	Yes	Yes	Yes
(Marsh and Adams, 1995)	4	Yes	Yes	Yes
(Moore, 1972)	6	YES	YES	YES
(Stone and Bacon, 1994)	4	Yes	Yes	Yes
(Paine and Hanlon, 2010)	6	Yes	Yes	Yes
TOTAL		29	29	0
LEVEL		HIGH	HIGH	HIGH

RELATIONSHIP 15.

Decreased carbohydrate reserves ➔ [increase] Abundance of secondary attackers

Plausible mechanism explaining the relationship

Severe and repeated defoliation by insects, resulting in reduced carbohydrate reserves, has been shown to result in an increase in attack by secondary pests and diseases. Moore (1962) reported increased attack of eucalypts by the ambrosia beetle (*Amasa truncata*) following repeated severe defoliation by *Glycaspis.* Old et al. (1990) reported that artificial defoliation of seedlings and saplings, and severe insect defoliation of mature native trees — both leading to a significant reduction in soluble and stored carbohydrates — resulted in increased canker development of *Endothia gyrosa* and *Botryospaheria ribis.* The authors suggested that these canker fungi may play an important role in tree dieback following repeated sever defoliation by insects.

Assessment of support for hypothesis

Conclusions based on table below: *Insufficient evidence to support the hypothesis*

Study	**Study weight**	**Response**	**Dose-response**	**Consistent with relationships?**
(Moore, 1962)	4	Yes	No	Yes
(Old et al., 1990)	4	Yes	Yes	Yes
TOTAL		8	4	0
LEVEL		LOW	LOW	HIGH

RELATIONSHIP 16.

Abundance of secondary attackers ➔ [increase] Defoliation

Plausible mechanism explaining the relationship

Secondary pests and diseases attack trees weakened by repeated defoliation and starved of carbohydrate reserves. Attack of severely defoliated trees by ambrosia beetles was associated with dead lower branches and reduced crown foliage. Old et al. (1990) observed an increase in canker fungi following repeated defoliation, and this led to further defoliation via girdling of branches and dieback.

Assessment of support for hypothesis

Conclusions based on table below: *insufficient evidence to support hypothesis.*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Moore, 1962)	4	Yes	No	Yes
(Old et al., 1990)	4	Yes	Yes	Yes
TOTAL		8	8	0
LEVEL		LOW	LOW	HIGH

RELATIONSHIP 17.

Increased defoliation (after repeated defoliation and exhaustion of carbohydrate reserves) ➔ [increases] Tree death

Plausible mechanism explaining the relationship

Several studies have shown that repeated, severe defoliation by insects (or artificial crown removal) can exhaust carbohydrate reserves due to ongoing crown regeneration — and lack of carbohydrate replacement via photosynthesis due to lack of photosynthetic organs — leading to tree mortality. Bamber and Humphreys (1965) measured starch content in phastmatid-attacked native forest trees: trees that had recently died due to repeated phasmatid attack had no starch in the sapwood, with successive defoliation and crown replacement events exhausting starch reserves with no replacement due to lack of photosynthetically active leaves. Severe defoliation of paddock trees, mainly by herbivorous insects, results in production of epicormic growth favoured by insects, then further defoliation, leading to depletion of carbohydrate reserves and eventual dieback and likely tree death (Landsberg and Wylie, 1983). Wills et al. (2004) reported that even after over 15 consecutive years of complete defoliation, *E. marginata* saplings did not die, although about half the saplings died back to almost ground level. Wills et al. (2004) discussed (references within) the variation in impact of severe defoliation among *Eucalyptus* species, with some species able to cope (e.g. *E. grandis, E. globulus*) while others more severely affected (e.g. *E. regnans, E. nitens*).

Assessment of support for hypothesis

Conclusions based on table below: *Support for hypothesis*

Study	Study weight	Response	Dose-response	Consistent with relationships?
(Bamber and Humphreys, 1965)	8	Yes	Yes	Yes
(Landsberg and Wylie, 1983)	8	Yes	Yes	Yes
(Wills et al., 2004)	6	Yes	Yes	Yes
TOTAL		22	22	0
LEVEL		HIGH	HIGH	HIGH

Alternative causal pathways

The review team acknowledges that there are alternative hypotheses about the causes of dieback traditionally described as BMAD affected forest. The alternative most commonly referred to in the literature involves the exclusion of fire leading to nutrient build-up in the soil and those nutrients affecting tree growth. It is hypothesised that sick trees produce high quality food that allow pests and diseases to take hold (Jurskis, 2005).

Effectively this hypothesis refutes the existence of a distinctive BMAD process; it is said to explain all forms of dieback, including dieback from dryland salinity, high-altitude dieback in Tasmania, BMAD, phasmatid outbreaks in NSW and Victoria, koala dieback in Victoria and South Australia, and rural dieback (Jurskis and Turner, 2002). While it was not an objective of this review to assess the validity of dieback pathways outside of BMAD, the analysis undertaken can offer the following insights into this alternative pathway.

- A considerable proportion of sites with BMAD identified via aerial mapping occur on wet sclerophyll vegetation in moist gullies. It is unlikely that exclusion of fire has dramatically changed the frequency of fire at these sites, however this does not exclude fire exclusion as a cause of BMAD at all sites and the effect of reducing fire frequency on understorey density does form part of the causal hypothesis in this review.
- There are multiple assessments in the literature that the nutrient theory is not supported by data from BMAD sites (e.g. Wardell-Johnson et al., 2005, Nageli et al., 2016, Lambert, 2015).
- Papers that describe this theory appear to rely significantly on citations of papers that do not include primary data, making the current evidentiary base weak. These studies were not scientifically designed nor contained primary data and as such did not fit the “inclusion criteria” (see Page 12). Moreover, what data is supplied does not include specific data on fire-frequency, soil nutrient levels, etc. (e.g. Jurskis and Turner [2002] Appendix 1).
- There are multiple cases at BMAD sites where woody weeds have been controlled without fire and this has led to a recovery of vegetation. This would not likely occur if soil nutrients were the primary driver of the dieback at these sites.

It is well established that there are multiple forms of eucalypt dieback, and it is critical that only sites where bell miner colonies and (mainly) psyllid infestations exist are described as potential BMAD sites. By adopting this approach, it does not preclude evidence that a more generic theory does apply to sites with BMAD conditions. In contrast, using evidence from non-BMAD sites to develop a hypothesis introduces the potential for incorrect exclusion of a BMAD specific causal pathway.

As stated above, this is not to say that the exclusion of fire many not be implicated in BMAD. It is quite plausible that the exclusion of fire (itself an intervention) may promote the growth of dense understorey and lead to dense bell miner colonies at some sites. This has been included as a specific relationship.

Recommendations in this report relating to testing the causal hypothesis are put forward here. Some of these measures would further clarify the level of cause attributed to pathways leading from the exclusion of fire.

Status of the current evidence base

Overall there has been a significant but piecemeal investment in research to address BMAD. There has been considerably more investment in the causes of BMAD than experimentation to improve the effectiveness of interventions.

An overwhelming response from people that engaged with this review spoke about the complexity of BMAD. BMAD does have a degree of complexity above many threatening processes, however the poor design and quality of much (not all) research has contributes to this. Added to this is a significant quantity of ‘secondary research’ that make claims unsubstantiated by reliable data or cherry-picking data.

Future investment in R&D on the causes of BMAD must be made in a coordinated effort to address high priority questions. Only high-quality experiments will lead to increased certainty. This includes the governance of projects to ensure perceptions of bias are minimised.

Like any management issue, a lack of understanding of the problem can result in incorrect selection and design of interventions and BMAD is no exception. It is essential that the primary causal pathway of BMAD is confirmed. The review team believes this can be achieved.

2.3.2 What are the economic, social and ecological impacts of BMAD? (Q2)

Of the literature searches undertaken, only seven evidence items were identified as relevant to reviewing the economic, social and ecological impacts of BMAD. These items are summarised in Table 6. Due to the low quantity of evidence no meaningful synthesis could be undertaken.

Table 6. Evidence containing information about the economic, social and ecological impacts of BMAD.

Citation	Reference	Key relevant points
(Ford-Thompson et al., 2012)	Ford-Thompson, A.E.S., Snell, C., Saunders, G., White, P.C.L., 2012. Stakeholder participation in management of invasive vertebrates. Conservation Biology 26, 345–356.	• Survey of managers of participatory vertebrate pest management programs. • One of the managers worked on a Bell miner program (so lowest possible sample size). • Survey participant identified level of importance of motivators for action for Bell miner as environmental effects (5/5), economic effect (4/5), social effects (2/5), and level of stakeholder conflict (4.5/5). • This was the highest stakeholder conflict assessment for any invertebrate pest.
(Meek, 2008)	Meek, P.D., 2008. Eucalypt decline and dead trees: if it's not sexy few seem to care. Pacific Conservation Biology 14, 240–241.	Provides estimates of the following impacts: a) CO2 losses (15 million tonnes per year estimated) b) NSW honey production ($21 million) c) Timber production $800-$3000/ha.
(Moore, 1962)	Moore, K.M., 1962. Entomological research on the cause of mortalities of Eucalyptus saligna Smith (Sydney blue gum). Research Notes. Division of Forest Management, Forestry Commission, NSW.	• Provides an assessment of commercial timber affected by *Glycaspis baileyi* and *Xyleborus truncatus* infestations. • The paper does not mention Bell miner, however it is included to give an indication of timber production lost to psyllid infestation that results from BMAD. • Two sites, 2.4 and 1.05 acres, were assessed and 57% of the trees were dead, representing 25,565 super feet hoppus.

Citation	Reference	Key relevant points
(Pearce et al., 1995)	Pearce, J., Menkhorst, P., Burgman, M.A., 1995. Niche overlap and competition for habitat between the helmeted honeyeater and the Bell miner. Wildl. Res. 22, 633–645.	• There is little overlap in niche habitats of the helmeted honeyeater and Bell miners. • This was modelled and then supported by the fact that the helmeted honeyeater does not expand into all of the territory held previously by Bell miners. • This is an example of the Bell miner affecting threatened species populations even when the habitats do not overlap.
(Pearce and Minchin, 2001)	Pearce, J., Minchin, P.R., 2001. Vegetation of the Yellingbo Nature Conservation Reserve and its relationship to the distribution of the helmeted honeyeater, Bell miner and white-eared honeyeater. Wildl. Res. 28, 41–52.	• Bell miner preferred habitat not usually overlapping with helmeted honeyeater. • Habitat reduction for both species is forcing overlap of territories.
(West and Podger, 1980)	West, P.W., Podger, F.D., 1980. Loss in timber volume and value due to regrowth dieback of eucalypts in southern Tasmania. Australian Forestry 43, 20–28. doi:10.1080/00049158.1980.10674241	• Based on a dieback site but was not BMAD. • Is included to provide an idea of losses when dieback occurs. • Loss of timber production m^3 over 11 years; $/ha was provided. • Maximum was 142 m^3; $499/ha in 1980 values.
(Woinarski and Wykes, 1983)	Woinarski, J.C.Z., Wykes, B.J., 1983. Decline and extinction of the Helmeted Honeyeater at Cardinia Creek. Biological Conservation 27, 7–21.	• Paper discusses the reasons for the probable extinction of the helmeted honeyeater from a site in the Dandenong Ranges, Victoria. • A hypothesis is put forward that changes to drainage lines made eucalypts susceptible to psyllid attack, which in turn supported the expansion of Bell miner colonies.

The two main impacts of dieback covered in these items are:

- impacts on threatened species
- impacts on commercial timber production.

Clearly both of these impacts are relevant to BMAD. Recommendations related to this are provided in the following section.

2.4 Recommendations

What causative factors lead to BMAD? (Q1)

The current evidence base provides the most support for the hypothesis that a variety of activities results in unnatural levels of understorey and mid-storey vegetation density (both exotic and native) and that this supports unnaturally low mortality of Bell miner nestlings.

Activities that could cause this include exclusion of fire, clearing for infrastructure including roads, pipelines and housing, and timber harvesting.

To confirm that this causal pathway is a primary driver of BMAD it is recommended that an experiment be established to test the impact of altering understorey and mid-storey density. To test the hypothesis adequately the experiment should include the following considerations. Please note that these considerations relate to this question only and others relating to intervention effectiveness are discussed later in this report.

1. 'Active' but not 'late-stage' BMAD sites should be selected. To be an active BMAD site the site must have a significant Bell miner colony, dense understorey/mid-storey and a psyllid infestation with signs of eucalypt tree dieback. Late stage BMAD sites should not be selected as the hypothesis predicts canopy improvement may be impossible due to the starch threshold being breached.
2. Treatment must be manual removal of plants so that site disturbance can be minimised. This is essential as site disturbance will introduce confounding factors that may activate other causal pathways. Treatment must occur in areas with existing nesting sites.
3. Site assessment must include:
    a. condition of the canopy (tree species / crown condition)
    b. change in the density of understorey and mid-storey
    c. bell miner population
    d. psyllid population
    e. soil and leaf nutrient testing (this is essential for removing the potential of other casual pathways)
    f. soil moisture or indicator of such as a topographic wetness index.
4. Experiments should not be commenced in periods of excessive weather (i.e. drought or flood)
5. Sites should be geographically diverse to allow for climatic variances to be controlled in the analysis.
6. A statistical analyst should be directly involved in experimental design to ensure the number of sites (both treatment and control) provide for significant power of analysis.
7. Representatives of different BMAD hypothesises should be provided with the opportunity to input to the experimental design so that confounding factors can be identified and controlled for.
8. Data collection should be undertaken by a group that would not lead to any perception of potential bias.

Low disturbance manual reduction of understorey will not activate alternative causal pathways (e.g. the nutrient/fire hypothesis), therefore if the interventions were implemented and monitored in a high-quality way, and were successful; the question of the primary causal pathway of BMAD would be substantially resolved. If the trials were unsuccessful and no obvious reasons for that are available then a second set of trials should focus on alternative potential causal pathways.

Recommendations: Question 1

R1(a): That the causal model presented in Section 2 of this review be adopted as a working hypothesis of BMAD in NSW.

R1(b): The causal model be established in an online setting where it can be readily updated and contributed to.

R1(c): A BMAD research and development program be established to answer a series of questions in a logical sequence to derive best practice management. The top priority for R&D investment should be to rigorously test the causal model that has been developed for this review.

What are the economic, social and ecological impacts of BMAD? (Q2)

Recommendations: Question 2

R2(a): An analysis be conducted to assess the overlap of DPI BMAD mapping with threatened flora and fauna in NSW.

R2(b): An analysis be conducted to assess the economic impact of BMAD on forestry operations in NSW State-owned forests. Note this should be linked to the research proposed in R4(a).

3: Interventions to treat BMAD

3.1 Introduction

BMAD interventions provide us with evidence to guide management practices and assist with the testing of causal models. The intervention related questions presented in this section of the review are as follows.

- **What are the most effective management interventions to control, prevent and restore BMAD? (Q3)**
- **What are the costs of intervention? (Q4)**
- **What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q5)**

3.2 Method

Outline of the method

Figure 5 outlines the major steps to collate and synthesise evidence related to questions in this section of the review.

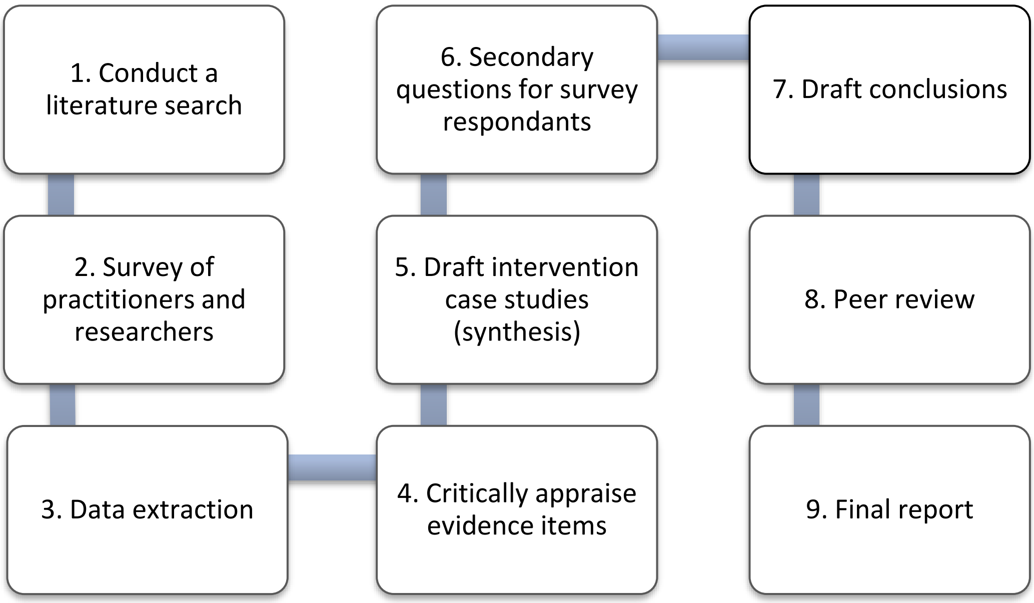

Figure 5. Steps in the method to review the evidence related to interventions to treat BMAD.

Step 1: Conduct a literature search

The same search string and sources were used as for the primary causal search presented in Section 2 of this review (6). Searches were undertaken in English and were not restricted by publication date.

Table 7. Search strings and sources

Source	Search string	Date of search
Web of Science	"Bell miner*"	21 July 2016
Trove (book type only)	"Bell miner*"	23 July 2016
Google Scholar	"Bell miner*"	21 July 2016

* is the Boolean search modifier for a root word, stem, or truncation search.

Bibliographic databases

The following bibliographic databases were searched for publications:

- Thomson Reuter's (formally ISI) Web of Science™ Core Collection http://apps.webofknowledge.com/
- Trove http://trove.nla.gov.au/

Search engines

An Internet search in Google Scholar was conducted. All records were retained for screening using the inclusion/exclusion criteria.

Project Steering Committee literature

The Project Steering Committee contributed a collection of literature that they had collated.

Study inclusion criteria

After all of the search results were compiled and duplicate items removed, the remaining search results were screened and included/excluded according to the following criteria.

- *Relevant location*: Study must be from Australia.
- *Relevant language*: Study must be available in English.
- *Relevant subject*: Study must include the application of a treatment for BMAD.
- *Primary data*: Documents that utilise data from other studies (i.e. are secondary research) will only be included if the primary source study cannot be found.
- *Study design:* Given the low quantity of evidence fitting the above criteria, no exclusions will be made based on study design of primary data. Purely anecdotal evidence will also be included.

Step 2: Survey of practitioners and researchers

A survey was developed and sent using the online platform Survey Monkey. The survey was sent to 149 practitioners and researchers who were known to have some involvement with BMAD. Recipients were also encouraged to send the survey link on to others they knew that could provide responses.

The questions in the survey that related to this part of the review were:

Survey Q6. Are you aware of any sites where BMAD management controls are being, or have been, implemented? Yes/No

Survey Q7. Describe the BMAD control undertaken at each location. *Fields provided were as follows*:

- BMAD location
- Management intervention
- Scale of intervention (hectares)
- Results of the intervention
- Costs of the intervention ($/ha)
- Documentation about this intervention
- Land tenure(s)
- Main learning's from the intervention

Survey Q8. In your experience, does landholding size (e.g. small private land parcels versus large areas of public land) influence the selection of treatment options for BMAD?

Yes/No

If yes, please explain how landholding size influences BMAD treatment options.

Step 3: Data extraction

Literature search

Search results were assessed individually and coded to each of the review questions.

Survey of practitioners and researchers

Responses for the survey questions were collated digitally using the Survey Monkey export function.

Step 4: Critically appraise evidence items

Refer to Step 7 of Section 2.2 in this document for this method.

Step 5: Draft intervention case studies (synthesis)

Evidence identified related to interventions was synthesised into a series of case studies. These cases exist at specific places, so where there are multiple studies and anecdotes related to the same place they are presented together.

Each place is presented as a case study with the following information provided:

- Map of location
- Placename
- Coordinates (decimal degrees)
- Land tenure
- Intervention type
- Intervention
  - Year
  - Works undertaken
  - Monitoring
  - Costs
- Synopsis of results
- Key lessons
- Source evidence
  - Citation
  - Reference
  - Type of evidence
  - Critical appraisal
- Consistency with causal model

Step 6: Secondary questions for survey respondents

In cases where there were gaps in the draft case studies the people who submitted or were involved with the case study were contacted for additional information. In some cases, this also provided additional documents related to the case study.

Step 7: Draft recommendations

A set of recommendations was drafted based on the evidence included in the review.

Step 8: Peer review

The BMAD Project Steering Committee reviewed the draft report.

Step 9: Final report

Comments from the review process were assessed and relevant changes were made before delivering the final report to the BMAD project Steering Committee.

3.3 Results and discussion

3.3.1 What are the most effective management interventions to control, prevent and restore BMAD? (Q3)

Data from the literature search and online survey was extracted and synthesised into a series of 20 intervention case studies, which are described individually below. Figure 5 shows the case study locations. The intervention case studies form four main locality groupings: the NSW/QLD border, the north coast of NSW, the Sydney and lower Hunter Valley catchments, and the ranges to the east of Melbourne.

Figure 5. BMAD intervention case study locations

The most common BMAD intervention (75 per cent of cases) was weed control; either the use of herbicide, mechanical removal or fire. Twenty-five per cent of interventions involved the physical removal of Bell miner colonies.

Table 8 presents a subjective analysis of the level of effectiveness of intervention for each case study. Given the complexity of BMAD, the rates of effective intervention are somewhat surprising. Only 5 per cent of cases could be described as 'not effective', while 60 per cent were effective.

The case study results were assessed against the hypothesis put forward in Section 2 that dense understorey facilitates higher survival rates of Bell miner nestlings. It was the assessment of the review team that the causal model adequately explains the results of all cases studies, including those that were not effective.

Table 8. Subjective level of effectiveness for weed control and Bell miner colony removal interventions.

	Type of intervention		
Level of effectiveness	**Weed control cases (n=15)**	**BM removal cases (n=5)**	**All cases (n=20)**
Not effective	1 (6.67%)	0 (0%)	5%
Partially effective	2 (13.33%)	1 (20%)	15%
Effective	8 (53.33%)	4 (80%)	60%
Not enough data to assess	4 (26.67%)	0 (0%)	20%

Status of the current evidence base

Overall, the evidence base to identify effective BMAD interventions is of low quantity and poor quality. There have been very few studies conducted to a high standard and many are not conducted over a long enough time scale, often due to funding or institutional constraints. For this reason the review team could not remove cases based on the quality of evidence even though critical appraisal was conducted.

Even though the quality of most methods used to assess the effectiveness of interventions is poor, there have still been a number of good lessons learned that should be taken into account when management advice is put forward. These lessons have been drawn on to develop the management recommendations in Section 3.4.

CASE STUDY 1	Mt Lindesay State Forest Compartments 276, 279 and part 280	
	Intervention type: Weed control (multiple methods) and replanting.	**Coordinates:** -28.3563614,152.6812301 (approx.)
	The intervention was: Not effective	**Land tenure:** State Forest

Intervention(s)

Year	Works undertaken	Monitoring	Costs
2007	Interventions were selected using a decision tree and involved combinations of: • harvesting • selective removal of shrubs and vines (mainly Lantana and Cissus) • ground preparation • burning • planting • reintroduction of low intensity fire.	Bell miner population and tree regeneration were monitored before treatments in 2007 and after treatments in 2008 and 2009.	$2,200/ha at 750 stems/ha; $2,500 at 1,000 st/ha; and $3,000 at 1,500 st/ha. Where there was some natural regeneration and moderate levels of lantana, costs were less than $1,000/ha, based on planting 500 trees

Synopsis of the results

Bell miner were strongly correlated with Lantana. Only the intensive fire had a lasting impact on the Lantana, however this has the potential to make the dieback worse. Lantana regenerated rapidly from low and moderate intensity fire. Treatments did not appear to improve the health of the retained trees.

Key lessons

- Low intensity fires are not likely to be effective against lantana once it is established, but note concerns about side-effects of high intensity fires.
- Sites that are in a dieback phase are unlikely to have the seed bank/drop required to support rehabilitation without planting.
- Planting out of sites is expensive.

Source evidence

Citation	Reference	Type
(FCNSW, 2015)	FCNSW, 2015. FCNSW BMAD adaptive management trials: results summary. Forestry Corporation New South Wales.	Unpublished report
(StClair, 2010)	StClair, P., 2010. Rehabilitation of declining stands at Mt Lindesay: a preliminary assessment. Australian Forestry 73, 156–164. doi:10.1080/00049158.2010.10676321	Scientific article

Consistency with causal model

The high level of correlation between Bell miner numbers and Lantana is consistent with the causal model. Given the monitoring undertaken and the complexity of the experimental design it is difficult to assess the consistency with the causal model.

CASE STUDY 2	Donaldson State Forest, New South Wales	
	Intervention type: Weed control (multiple methods) and replanting	**Coordinates:** -28.3652737,152.6067291 (approximate)
	The intervention was: Partially effective	**Land tenure:** State Forest

Intervention(s)

Year	Works undertaken	Monitoring	Costs
2006	In 2005 the BMAD Working Group determined to help fund trials of Lantana control on Donaldson State Forest as one of three trials of using understorey control to redress BMAD. A control was established along with three weed control treatments of: • combined fire and mechanical removal • mechanical understorey removal • fire.	16 plots, 4 sampling sessions collecting: • lantana % cover • Bell miner abundance.	$2,200 per hectare at 750 stems per hectare; $2,500 per hectare at 1,000 stems per hectare; and $3,000 per hectare at 1,500 stems per hectare. Where there was some natural regeneration and moderate levels of Lantana, costs were less than $1,000 per hectare, based on planting 500 trees (Nicholls, 2008).

Synopsis of the results

The following is from Pugh, (2014):

A review of the Bell miner data provided by the Forestry Corporation to the BMAD Working Group for four replicates each of three treatments and a control, apparently seven months after logging, indicate a 39% (27-66%) reduction in Bell miner numbers on the controls, compared to an average 73% (11-95%) decline on the treated sites.

Shipman (2007) revisits the Donaldson State Forest site that was treated with fire and mechanical weed control. The other two treatments were not reported on in this document. Results include:

- 'The whole of the treatment area had weeds recorded in all plots and the density of them was calculated as being near 10,000 stems per hectare (st/ha), with 189 lantana (st/ha), 27 Cissus (st/ha) and 4600 (st/ha) of wattles (Acacia species) all competing against eucalypt seedlings for survival.'
- 'The "Cottam Curtis Method" calculated that there are 420 stems per hectare.' This is a relatively low number for Eucalypt regeneration.
- 'The average basal area of eucalypts (ignoring non-commercial species) in the surrounding forest (shown in Figure 3), is approximately double that of the treatment area. The surrounding forest was of the same forest type and structure as the treatment area prior to treatment.'
- The regeneration of canopy trees in the treatment area was poor.

Key lessons

- Sites that require replanting will be costly to restore. Maintenance needs to be conducted at rehabilitation sites if replanting or natural regeneration are to succeed.

- Care needs to be taken when designing field trials to ensure results can improve the evidence base (i.e. answer specific questions).
- Governance of government funded trials needs to be strong to ensure that project objectives are fulfilled.

Source evidence

Citation	Reference	Type
(FCNSW, 2015)	FCNSW, 2015. FCNSW BMAD adaptive management trials: results summary. Forestry Corporation New South Wales.	Unpublished report
(Pugh, 2014)	Pugh, D., 2014. For whom the Bell miners toll. North East Forest Alliance.	Unpublished report
(Shipman, 2006)	Shipman, R., 2006. Regeneration/treatment of Bell miner associated dieback in native forests (Unpublished third year undergraduate report). School of Environmental Science and Management, Southern Cross University, Lismore, New South Wales, Australia.	Unpublished report
(Nicholls, 2008)	Nicholls, D., 2008. Northern NSW: The spread of lantana threatens the natural balance. Australian Forest Grower 31, 38.	Scientific article

Consistency with causal model

A reduction in Bell miner numbers after the reduction to understorey density is consistent with the causal model.

CASE STUDY 3	Toonumbar National Park, north coast of New South Wales	
	Intervention type: Weed control using herbicide	**Coordinates:** -28.4872053,152.7294824 (Park not site location)
	The intervention was: Partially effective	**Land tenure:** National Park

Intervention(s)

Year	Works undertaken	Monitoring	Costs
2005	Lantana was treated using herbicide delivered by a splatter gun.	The Bell miner population was monitored over ten years. Density of understorey, mid-storey and canopy were assessed.	Not provided. See Creeks Bend for costs.

Synopsis of the results

The splatter gun was a successful lantana treatment, however Bell miners persisted at the site. This is in contrast to the adjacent identical treatments at Creeks Bend where Bell miner numbers gradually reduced from 2005 to 2011. The potential explanation provided is that the Toonumbar site still had a dense understorey following rehabilitation, so the high quality nesting sites were not removed by removing the lantana.

Key lessons

- Splatter guns are effective at treating Lantana at two different sites.
- If a dense understorey remains after weed control Bell miner colonies may persist.
- When planning rehabilitation it is important to ensure sites have a viable native seed bank to regenerate from otherwise the canopy may not repair.
- Dense lantana requires multiple applications of treatment to effectively control

Source evidence

Citation	Reference	Type
(Lambert et al., 2016)	Lambert, K., Kumar, L., Reid, N., McDonald, P.G., 2016. Habitat selection by a despotic passerine, the Bell miner (Manorina melanophrys): when restoring habitat through Lantana (Lantana camara) removal is not enough. Ecol Manag Restor 17, 81–84. doi:10.1111/emr.12196	Scientific article

Consistency with causal model

The explanation of the intervention failing at Toonumbar but not Creeks Bend is consistent with the causal model as dense understorey with high leaf cover remained after the intervention. So long as the vegetation structure supports survival rates above normal levels then the density of the colony will be high.

CASE STUDY 4	Creeks Bend, north coast of New South Wales	
	Intervention type: weed control using herbicide	**Coordinates:** -28.4872053,152.711973
	The intervention was: Effective	**Land tenure:** private

Intervention(s)

Year	Works undertaken	Works done by	Costs
2005	Lantana control using a splatter gun. Old forestry tracks were pushed through and side 20m treated from a modified 4WD. Follow up treatment on foot with backpack. A 9:1 high concentrate glyphosate was used.	Managed by Susan and Wayne Somerville.	$250 per hectare and potentially decreasing.

Synopsis of the results

Treatment of approximately 300 hectares of Lantana was successful with a splatter gun. Follow up treatment was required at sites that had more disturbance history and higher initial infestation levels. Herbicide was more effective at wetter sites. Bell miner numbers reduced at three of the five sites. The two sites without change still had nearby nesting sites as the Lantana was only just being treated. The treatment program continued for five years following a set of successful trials.

Key lessons

- Splatter gun is an effective and relatively cheap method of Lantana control.
- Lantana removal may not be effective in small patches if there are adjacent nesting sites for Bell miners.
- Demonstrates the practicality of splatter gun control on a landscape scale with innovative advances such as the 4WD mounting system.
- Dense lantana requires multiple applications of treatment to effectively control

Source evidence

Author/provider	Reference	Type
(Somerville et al., 2011)	Somerville, S., Somerville, W., Coyle, R., 2011. Regenerating native forest using splatter gun techniques to remove Lantana. Ecological Management & Restoration 12, 164–174.	Scientific article
(Lambert et al., 2016)	Lambert, K., Kumar, L., Reid, N., McDonald, P.G., 2016. Habitat selection by a despotic passerine, the Bell miner (Manorina melanophrys): when restoring habitat through Lantana (Lantana camara) removal is not enough. Ecol Manag Restor 17, 81–84. doi:10.1111/emr.12196	Scientific article

Consistency with causal model

Highly consistent with the causal model. Lantana removal that resulted in removal of Bell miner colonies did result in vegetation condition improvement.

CASE STUDY 5	Blue Knob, near Lismore, New South Wales	
	Intervention type: weed control and replanting	**Coordinates:** -28.5487126,153.1752653 (approx.)
	The intervention was: Effective	**Land tenure:** private

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
Ongoing	Weed control and replanting across 8ha using fast growing flowering natives.	Not provided.	$2,500

Synopsis of the results

The diversity of birdlife on the property has not seen any notable change over a 26-year period. The bell miners appear to stay on the boundary of the property, which is surrounded by larger properties. BMAD is continuing to spread on local properties without active management.

Key lessons

- Weed control and a diverse forest community appear to be keeping the BM and dieback from encroaching from surrounding properties.
- Lack of coordinated weed control across property boundaries is making ongoing management very difficult.

Source evidence

Citation	Reference	Type
Pelly 2016	Ms. Vanessa Pelly, pers. comm. via survey Nov. 2016	Pers. comms.

Consistency with causal model

This result is consistent with the causal model. Weed management is not allowing for high-density Bell miner colonies to establish and therefore dieback is not encroaching onto the property.

CASE STUDY 6	Jiggi, near Lismore, New South Wales	
	Intervention type: Weed control	**Coordinates:** -28.7097888,153.1511312 (approx.)
	The intervention was: Effective	**Land tenure:** Private

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
2011 ongoing	Lantana understory control and applying for funding to extend work. Work undertaken on a 10ha area.	Casual observation	Not provided.

Synopsis of the results

No BMAD affecting eucalypts on sites managed to control Lantana but impacts of BM are evident on adjoining properties with no management in place.

Key lessons

- Don't open the canopy to allow lantana to proliferate, this occurred when a landowner adjoining work sites, cleared a huge swathe of native eucalypts to construct a road. The road never happened but lantana replaced the mature vegetation and BMAD area increased.

Source evidence

Citation	Reference	Type
Reid 2016	Ms. Julie Reid, pers. comm. via survey Nov. 2016	Pers. comms

Consistency with causal model

This is consistent with the causal model that predicts BMAD will only occur in areas of dense understorey or mid-storey.

CASE STUDY 7	Busby's Flat, New South Wales	
	Intervention type: Weed control (fire) and bush regeneration	**Coordinates:** -29.083876,152.770456
	The intervention was: Effective (preliminary data)	**Land tenure:** Local Aboriginal Land Council (LALC) property

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
2016	Low intensity burns have been applied in an effort to reduce the nesting sites for BM (i.e. dense mid-stratum of rainforest pioneers and lantana) and the threat of an intense bush fire. Bush regeneration techniques have also been applied across 43ha. For more information refer to: http://www.nrfabcon.org.au/projects/busby-s-flat-project http://www.firesticks.org.au/protecting-the-high-ecological-and-cultural-values-of-busbys-flat/	Pre-burn monitoring: • rapid floristic survey documenting structure and floristics of each strata • photo monitoring at established photo points. Post-burn monitoring: • 1 month after fire - photo monitoring. • 12 months after fire – to be completed	Not provided.

Synopsis of the results

The monitoring program is still in the early days, but preliminary results include:

- The burns have reduced critical nesting habitat for Bell miners, by reducing cover and height of mid-storey, including rainforest saplings and lantana.
- Areas of dense Lantana and rainforest saplings were not consumed during the burns, presumably because the dense shade created by this dense mid-storey has suppressed the flammable ground layer vegetation (i.e. grasses, sedges and fine-leaved shrubs) necessary to carry the low intensity fire.
- It is not yet known to what extent rainforest saplings and lantana will re-sprout or regenerate from seed following the burns.

Key lessons

- Fire can be successfully used to reduce/remove the mid-stratum of rainforest pioneers and lantana that provide the critical nesting sites for Bell miners.
- Critical thresholds in the transition of healthy open forest to BMAD affected forest occurs where the mid-stratum shades out the flammable understorey, thereby reinforcing the transition and precluding the use of fire in mild fire weather.

Source evidence

Citation	Reference	Type
Baker	Mr. Andy Baker, pers. comm. via survey Nov. 2016	Pers. comms

Consistency with causal model

Too early to assess.

CASE STUDY 8	Jaaningga Nature Reserve	
	Intervention type: Weed control and rehabilitation	**Coordinates:** -30.5184551, 152.9535687
	The intervention was: Not enough data to assess effectiveness.	**Land tenure:** Crown land

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
Not provided.	Removal of lantana infestations, restoration of native mid storey and restoration of a more natural forest structure. Works undertaken across a 5 ha area.	Not provided.	Not provided.

Synopsis of the results

There has not been sufficient time since the intervention to provide results.

Key lessons

- Too early to identify

Source evidence

Author/provider	Reference	Type
Smith 2016	Mr. Martin Smith, pers. comm. via survey Nov. 2016	Pers. comms

Consistency with causal model

Too early to assess.

CASE STUDY 9	Kumbatine National Park (Main Range Trail & Kippara Ranger Trail)	
	Intervention type: Weed control (fire).	**Coordinates:** -31.1720957,152.6462174 (approx.)
	The intervention was: Not enough data to assess effectiveness.	**Land tenure:** National Park

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
Not provided.	Ecological burning to control lantana. Trapping and tagging birds. Works conducted over approximately 1800ha.	Could not be monitored as funding was removed from the project.	Not provided.

Synopsis of the results

Not provided.

Key lessons

- Unable to identify due to lack of results.

Source evidence

Citation	Reference	Type
Wyatt 2016	Ms. Alexandra Wyatt, pers. comm. via survey Nov. 2016	Pers. comms

Consistency with causal model

Unable to assess due to lack of results.

CASE STUDY 10	"Glen Grant", Enfield North Road, Nowendoc, New South Wales	
	Intervention type: Weed control (mechanical and fire).	**Coordinates:** -31.4472729,151.9189866 (approx.)
	The intervention was: Not enough data to assess effectiveness.	**Land tenure:** Private

Intervention(s)

Year	Works undertaken	Monitoring undertaken	Costs
2016	Limited mechanical disturbance/trampling of understorey and introduction of fire.	Casual observation	Low cost - associated with timber harvesting event and subsequent hazard reduction burning.

Synopsis of the results

It is too early to tell as the interventions have only recently been implemented.

Key lessons

- Too early to identify.

Source evidence

Citation	Reference	Type
Dobbyns 2016	Mr. Steve Dobbyns, pers. comm. via survey Nov. 2016	Pers. comms.

Consistency with causal model

Too early to assess.

CASE STUDY 11	Olney State forest, near Wyong, New South Wales	
	Intervention type: Bell miner exclusion and insecticide.	**Coordinates:** 33.113523, 151.303353
	The intervention was: Effective	**Land tenure:** State forest

Intervention(s)

Year	Works undertaken	Monitoring	Costs
1994	Bell miners were excluded using cages around branches. Insecticide via direct stem injections were applied and then a combination of both was applied as a third treatment.	Monitoring of leaf area, leaf damage, leaf presence/absence, trunk diameter and crown condition. The intervention occurred in 1994 and monitoring occurred up to 1995. Note the study was designed to investigate parts of the BMAD causal process as opposed to intervention effectiveness but the study still provides useful treatment insights.	Not provided.

Synopsis of the results

Exclusion of Bell miner more than doubled leaf life expectancy in 3 of 4 tested trees. Note the fourth tree had much lower density of BM to start with, which could explain the difference. Insecticide application significantly reduced the % of leaf area lost to chewing and necrosis. Did not produce a significant improvement in trunk diameter or crown condition. Combination of the two treatments did result in significant increase in tree trunk diameter the development of adult leaves.

Key lessons

- Bell miners can directly decrease the life expectance of leaves.
- A combination of interventions can be more effective at some sites.

Source evidence

Author/provider	Reference	Type
(Stone, 1996)	Stone, C., 1996. The role of psyllids (Hemiptera: Psyllidae) and Bell miners (*Manorina melanophrys*) in canopy dieback of Sydney blue gum (Eucalyptus saligna Sm.). Australian Journal of Ecology 21, 450–458. doi:10.1111/j.1442-9993.1996.tb00631.x	Scientific article

Consistency with causal model

The ability of Bell miners to reduce the predators of leaf-eating insects is consistent with the causal model.

CASE STUDY 12	Bowen Mountain, Blue Mountains, New South Wales	
	Intervention type: Weed control (herbicide and fire)	**Coordinates:** -33.5787507,150.5526596
	The intervention was: Effective	**Land tenure:** Private

Intervention(s)

Year	Works undertaken	Monitoring	Costs
2015	Hotspots workshop participants were introduced to integrated fire and herbicide treatment to control lantana and developed integrated fire and weed management property plans. Follow up funding provided by the Greater Sydney Local Lands Services enabled on-ground regeneration works to address BMAD with several properties across the Bowen Mountain, Kurrajong and Grose Vale areas. Properties were strategically targeted based on integrated weed control activities required, extent of infestation, and the ability for sufficient resources to implement follow-up strategies for the long term. The regeneration works included splatter-gun, cut and paint and manual control to remove targeted weed species, patch burning and pre- and post-weed monitoring. Fire to be used when sufficient reduction of weed has occurred. Works were undertaken on approximately 3 ha.	Within each of the 10 1x1m quadrats groundcover values were recorded (as a % cover). The following attributes were recorded within the quadrat to the nearest 10% (total 100%): • Native groundcover (plants <1m) • Weeds (plants <1m) • Mosses and lichens • Organic litter • Rock/water/bare ground. Other attributes recorded across the 0.1ha plot included: • Canopy species (in order of dominance) • Length of fallen timber with a width of >10cm • Number of hollow • Evidence of recruitment of each dominant/canopy species	Not provided.

		• Canopy health (as a proportion of full health = 100% value) Numbers of native vine and shrub species and native groundcover species were recorded within a nested 20x20m floristic plot (Graham, 2017).	

Synopsis of the results

- Good regeneration of native plant species is occurring. Nature Conservation Council records vegetation data and photo points.
- Refer to Graham (2017) for more detail regarding summary of data responses to date.

Key lessons

- More detail needs to be gathered around this trial before key lessons can be derived.

Source evidence

Citation	Reference	Type
Smolski 2016	Ms. Kate Smolski, pers. comm. via survey Nov. 2016	Pers. comms.
(Graham, 2017)	Graham, M., 2017. Results of ecological restoration site monitoring: Bowen Mountain. Hotspots fire project.	Report

Consistency with causal model

More detail needs to be gathered around this trial before this can be assessed.

CASE STUDY 13	Pennant Hills, New South Wales	
	Intervention type: Weed control (manual bush regeneration)	**Coordinates:** -33.74485,151.03611
	The intervention was: Effective	**Land tenure:** Private

Intervention(s)

Year	Works undertaken	Monitoring	Costs
Not provided.	Manual clearing of exotics in the Blue Gum Forest remnant. Also used fire piles.	IBM Australia	Not provided.

Synopsis of the results

- There appears to have been an increase in wrens and whip birds (*Psophodes olivaceus*) during this time, and Bell miner numbers have decreased. A landscape management plan is in preparation and will be recommending ongoing resource allocation to the bush regeneration program.

Key lessons

- The method of understorey weeding (mechanical or fire) seems to be irrelevant to the impact on Bell miner populations.

Source evidence

Author/provider	Reference	Type
McDonald et al. 2002	McDonald, T., Wale, K., Bear, V., 2002. Restoring Blue gum high forest: lessons from Sheldon Forest. Ecological Management & Restoration 3, 15–27. doi:10.1046/j.1442-8903.2002.00093.x	Scientific article, but note this case was anecdotal.

Consistency with causal model

Not enough is known about this case to determine its consistency with the BMAD causal model.

CASE STUDY 14	Cumberland State Forest, New South Wales	
	Intervention type: weed control using manual removal and fire	**Coordinates:** -33.7447104,151.0381739
	The intervention was: Not enough data to assess effectiveness.	**Land tenure:** State forest

Intervention(s)

Year	Works undertaken	Monitoring	Costs
Not provided.	Blue Gum remnants in Cumberland State Forest have become very degraded in the last ten years. Disproportionate numbers of Bell miners (*Manorina melanophrys*) are also a serious problem, possibly due to excessive Lantana in the understorey. Trials have been conducted using mechanical disturbance followed by regeneration weeding. Fire piles were used on a trial basis.	Not provided.	Not provided.

Synopsis of the results

- Wattles and grasses not seen before treatments have established. No details are available about the impact on Bell miner populations.

Key lessons

- Not enough detail to extract key lessons.

Source evidence

Author/provider	Reference	Type
McDonald et al. 2002	McDonald, T., Wale, K., Bear, V., 2002. Restoring Blue gum high forest: lessons from Sheldon Forest. Ecological Management & Restoration 3, 15–27. doi:10.1046/j.1442-8903.2002.00093.x	Scientific article, but note this case was anecdotal.

Consistency with causal model

Not enough is known about this case to determine its consistency with the BMAD causal model.

CASE STUDY 15	"Mandeni" near Merimbula, New South Wales	
	Intervention type: Bell miner colony removal	**Coordinates:** -36.833333, 149.900000
	The intervention was: Effective	**Land tenure:** Private

Intervention(s)

Year	Works undertaken	Monitoring	Costs
2005	Bell miners were culled and the colony was successfully removed from the treatment sites. Tree health was measured afterwards in 2005 and 2006.	Tree health monitored 6-12 months after the intervention in 2005.	Not provided.
2011	No new intervention work, but tree health was re-assessed.	One off assessment of tree health in 2011.	Not provided.

Synopsis of the results

Bell miners were successfully removed. Tree health had not improved in the 6-12 months following Bell miner removal in 2005 (Dare 2010). However, Hastings re-assessed the trees in 2011 and found there had been a significant improvement in the treated trees.

Key lessons

- This case demonstrates the importance of long-term monitoring of tree recovery since it can take a number of years to occur.
- Bell miner culling/removal does not always result in re-colonisation of a treated site by other avian species.

Source evidence

Author/provider	Reference	Type
(Dare, 2010)	Dare, A., 2010. Processes influencing habitat selection in Bell miners *Manorina melanophrys* (PhD Thesis). La Trobe University.	PhD Thesis
(Hastings, 2012)	Hastings, T., 2012. Rainforests and Bell miner associated dieback in natural ecosystems (B. Env. Sc. Honours). Charles Sturt University, Wagga Wagga, New South Wales, Australia.	Honours Thesis

Consistency with causal model

The Dare (2010) original findings were inconsistent with the BMAD causal model, however the follow up assessment by Hastings identified changes consistent with the model. The discrepancy is adequately explained by the existence of the starch reserves that do require significant time to readjust.

CASE STUDY 16	Coranderrk Reserve near Healesville, Victoria	
	Intervention type: Bell miner colony removal	**Coordinates:** -37.683333, 145.516667
	The intervention was: Partially effective	**Land tenure:** Crown land

Intervention(s)

Year	Works undertaken	Monitoring	Costs
1993	189 Bell miners were removed from the site via netting and shooting. The experimental site was 50 x 50 m, however an additional habitat area of 2.7 ha was cleared of Bell miner to remove the colony.	Bell miner population, psyllid population and tree health were monitored over a 2.5-year period.	Not provided.

Synopsis of the results

Once most individuals from the Bell miner colony were removed the remaining birds ceased inter-specific territorial behaviour and eventually left the site. A range of new bird species that entered the site immediately devoured the Glycaspis spp. infestation. Individuals of non-Bell miner species trebled in 12 days following the removal. Bell miners returned within 10 months and tree health did not improve over the 2.5 years of monitoring.

Key lessons

- The Bell miner colony was excluding psyllid predators at this site.
- Bell miner removal can lead to rapid removal of psyllid infestations.
- If the causes of Bell miner density are not addressed, direct removal of the colony is only a short-term solution.
- Removal of Bell miner does not always result in vegetation improvement (see comments in causal model section below).

Source evidence

Citation	Reference	Type
Clarke and Schedvin, 1999	Clarke, M.F., Schedvin, N., 1999. Removal of Bell miners Manorina melanophrys from Eucalyptus radiata forest and its effect on avian diversity, psyllids and tree health. Biological Conservation 88, 111–120. doi:10.1016/S0006-3207(98)00083-4	Scientific article

Consistency with causal model

The reported events are consistent with the causal model. While the vegetation condition did not improve following removal of the Bell miners and psyllid infestation, the model predicts that this will occur in cases where the starch reserves of the trees breach an irreversible threshold. This is well established in the literature. An alternative explanation is that the trees did not have sufficient time to regenerate.

CASE STUDY 17	Olinda State Forest, near Melbourne, Victoria	
	Intervention type: Bell miner colony removal	**Coordinates:** -37.833333, 145.366667
	The intervention was: Effective	**Land tenure:** State Forest

Intervention(s)

Year	Works undertaken	Monitoring	Costs
1981	34 BM making up a small colony across 3ha were removed using mist-nets and relocated to a larger colony at a different site.	BM population, epicormic growth monitored 6 months after the removal of the BM population.	Not provided.

Synopsis of the results

Numbers of Glycaspis spp. declined rapidly (eaten by other birds) and remained near zero. Epicormic growth increased by 6% in the 6 months following compared to 4% in the control.

Key lessons

- Removal of BM can lead to a rapid reduction in psyllid numbers and increased epicormic growth in trees. This shows the power of common forest birds to control an insect infestation, and the efficacy of the Bell miners' territoriality in preventing other birds from decimating a food source.

Source evidence

Author/provider	Reference	Type of evidence
(Loyn et al., 1983)	Loyn, R.H., Runnalls, R.G., Forward, G.Y., Tyers, J., 1983. Territorial Bell miners and other birds affecting populations of insect prey. Science 221, 1411–1413. doi:10.1126/science.221.4618.1411	Scientific article

Consistency with causal model

Results are consistent with the causal model. Removal of the Bell miners resulted in an improvement in vegetation condition when compared to the control.

CASE STUDY 18	Dandenong Ranges (1), Victoria	
	Intervention type: Fire	**Coordinates:** No exact location provided.
	The intervention was: Effective	**Land tenure:** Public and private property

Intervention(s)

Year	Works undertaken	Monitoring	Costs
Not provided	Opportunistic bushfire (>10 ha) and planned intensive burn across approximately 20 hectares.	Not long term	Not provided.

Synopsis of the results

Trees lost most foliage from the fire along with psyllids and Bell miners. The trees recovered and were healthy (though in the wildfire instance this was from basal re-sprouting, as most above-ground stems were killed).

Key lessons

- When fire is intense enough to kill foliage, the psyllids (and associated Bell miners) will be lost from those sites, at least for the short-term.

Source evidence

Author/provider	Reference	Type
Loyn 2016	Mr. Richard Loyn, pers. comm. via survey Nov. 2016.	Pers. comms.

Consistency with causal model

Fire can be a causal mechanism for eliminating BMAD, at least in the short-term. These observations do not provide evidence for or against the BMAD causal model, but they show that it is not the only mechanism that needs to be considered by managers.

CASE STUDY 19	Dandenong Ranges (2), Victoria	
	Intervention type: Understorey removal	**Coordinates:** No exact location provided
	The intervention was: Effective	**Land tenure:** Private property

Intervention(s)

Year	Works undertaken	Monitoring	Costs
Not provided	Slashing of understorey weeds over approximately 2ha.	Unknown.	Not provided.

Synopsis of the results

BM retreated to nearby gullies. Psyllids and dieback reduced on remaining trees.

Key lessons

- Where practical slashing is an effective means of removing understorey and reducing BM numbers.

Source evidence

Citation	Reference	Type of evidence
Loyn 2016	Mr. Richard Loyn, pers. comm. via survey Nov. 2016	Pers. comms.

Consistency with causal model

The removal of understorey leading to a reduction in BM's and subsequent improvement in tree health is consistent with the causal model.

CASE STUDY 20	Yellingbo State Reserve, Upper Yarra Valley, Victoria	
	Intervention type: Bell miner colony removal	**Coordinates:** -37.85502, 145.49978
	The intervention was: Effective	**Land tenure:** Crown land

Intervention(s)

Year	Works undertaken	Monitoring	Costs
1989	Bell miners in colonies adjacent to the helmeted honeyeater were culled. This was done with the intent of aiding the recovery of the threatened honeyeater population.	Monitoring of BM and helmeted honeyeater prior to the cull in 1989 and then following the intervention up to 1991.	Not provided.

Synopsis of the results

Bell miners were significantly associated with high levels of eucalypt dieback. Immediately following the cull the areas were visited by the threatened Helmeted honeyeaters. They established 8 new territories within 13 months of bell miner removal. No data was found on changes to the status of dieback as a result of BM removal.

Key lessons

- High association of BM with dieback and shrubs.
- The inter-specific aggression of BM can have a considerable impact on local threatened bird species.
- Culling of BM colonies is a viable intervention to gain immediate results for threatened species being impacted.

Source evidence

Author/provider	Reference	Type
(Pearce et al., 1995)	Pearce, J., Menkhorst, P., Burgman, M.A., 1995. Niche overlap and competition for habitat between the helmeted honeyeater and the Bell miner. Wildl. Res. 22, 633–645.	Scientific article

Consistency with causal model

The ability of Bell miners to exclude other bird species is consistent with the causal model.

3.3.2 What are the costs of intervention? (Q4)

The review was only able to find costing for four of the twenty intervention case studies. The cheapest intervention was the splatter gun application of herbicide in the Creeks Bend case on the NSW North coast. This was estimated at $250 per hectare, with the potential to further reduce costs. It is important to note however that this cost does include in-kind contributions of labour by landholders.

A current estimate of costs for Lantana removal in severely affected forest in difficult terrain is $1,000 per hectare (Grant Gibson, pers. comm.). In cases where dieback is already established, the intervention costs will dramatically rise since there is insufficient natural seed bank remaining for a canopy to establish. The additional costs of seedlings of up to $3,000 per hectare for high-density plantings can be estimated.

The costs of not intervening also need to be considered. Apart from the loss of amenity and potential impact on native flora and fauna, there is also a potentially significant economic impact. Quite regardless of its association with BMAD, if the growth of plants such as lantana is left unchecked post-harvest, they severely restrict the natural regeneration needed to keep timber-harvesting operations sustainable. The costs of preventative weed management at these sites will be significantly cheaper than treating sites where BMAD is established (Grant Gibson, pers. comm.).

Overall, due to the small quantity of literature available related to BMAD interventions it is not possible to draw rigorous conclusions about a comparison of triple bottom line impacts of intervention types including passive management. What can be concluded though is that proper weed management as part of post-harvest site rehabilitation can be undertaken at a reasonable cost on a broad scale, particularly when the costs of not managing BMAD are considered.

3.3.3 What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q5)

Of the 64 survey responses, 24 believed landholding size does have an impact on BMAD treatment options. Nine survey respondents believed it did not. The remaining 31 survey respondents did not answer this question.

For those who responded ‘yes’, a selection of reasons and example quotes are provided in Table 9. Please note that the inclusion of these differences does not reflect a judgement on its accuracy.

The responses are relatively similar. For large public landholdings obtaining and planning the use of larger resources is difficult and the intervention options are reduced since intensive methods are not practical. For small private landholdings action is a lot easier to take and the intervention options are greater. However, when surrounded by other properties where management is not occurring, it is a never-ending process of management since no buffer can be created around their property.

Table 9. Differences given between developing BMAD interventions for small private vs large public land.

Difference identified	Example response
Smaller land holdings can apply a broader range of ‘intensive options’ that are not economically viable on larger sites.	*Small lands holdings have capacity to achieve removal and then management without fire. Large landholdings it become cost and labour prohibitive - fire is the most likely cost effective and achievable practice at larger scales.*
Small private landholders have less access to expertise to implement more complex options such as prescribed burns.	*BMAD is widespread across all tenures. Private landholders are generally uninformed and have limited resources to deal with the issue while public land affected is so large an area that no dept. has sufficient resources to tackle the problem in any meaningful way.*

Difference identified	Example response
Lack of financial resources for public land custodians	*Little money or willingness to undertake control at a landscape scale in NP's due to "lack of funding". State Forests are probably a bit better as they have a resource to secure and therefore a budget. Numerous landholders are self-motivated and or externally funded*
It takes more resources to plan action on large public landholdings	*In badly affected areas the use of large area treatments with fire, machinery or aerial spraying are more cost effective but can be complex and slow to plan and implement.*
Minimum area to attain a sustainable benefit of intervention.	*There is little point in trying to mitigate BMAD on a small property e.g. less than 10 hectares if the surrounding larger area is not treated. Birds/psyllid will still impact trees in treated area unless a relatively large area is treated.*

3.4 Recommendations

What are the most effective management interventions to control, prevent and restore BMAD? (Q3)

Recommendations: Question 3

Management recommendations

Evidence drawn from intervention case studies and the causal model provide a basis for the following practice recommendations. These recommendations should be regularly reviewed taking new evidence into consideration.

Prevention

For any activity* that disturbs susceptible vegetation communities:

R3(a): Disturbance of the canopy should be minimised where possible.

R3(b): Where the canopy is disturbed, rehabilitation should focus on re-establishment of a canopy as soon as possible to limit unnatural understorey density.

R3(c): Site rehabilitation should include ongoing management of invasive weeds, particularly those that minimise natural regeneration and can act as superior nesting sites for Bell miners. Note that in timber harvesting operations weeds such as lantana have been shown to dramatically impact on the economic viability of sites so improved management of weeds will not necessarily lead to a net negative financial outcome.

R3(d): Exclusion of fire is an artificial disturbance activity that can lead to woody weed invasion. Appropriate fire regimes should be designed and implemented. Note that a significant proportion of BMAD sites would not have had fire at regular intervals so this needs to be carefully implemented using the best available science, with appropriate environmental approvals and liaison with the Rural Fire Service.

*These preventative measures apply to activities that include: timber harvesting, clearing for roads and infrastructure, recreational activities that alter vegetation, and removal of natural fire regimes.

Treatment

R3(e): A site assessment should be undertaken to ensure that Bell miners are present and psyllid attack is the primary cause of dieback prior to investment in BMAD interventions. There are many other causes of eucalypt forest dieback. See R3(k) for more about development of a site assessment method.

R3(f): If the prevailing vegetation community is naturally dense in the understorey or mid-storey then consideration should be given to not intervening in the site as BMAD may be a natural process there.

Recommendations: Question 3 continued

R3(g): At sites with an unnatural level of understorey and/or mid-storey density the viability of the seed bank for rehabilitation without planting should be assessed. Many interventions have likely failed due to a lack of a viable seed bank. Sites requiring plantings will cost significantly more than sites without.

R3(h): In sites with high value assets being impacted by BMAD (e.g. threatened flora or fauna) consideration should be given to culling of Bell miners followed by site rehabilitation. This has been shown to have an immediate reduction on exclusion of other bird species for example.

R3(i): The primary aim of site treatment should be to reduce the occurrence of superior nesting sites for the Bell miner. The method best to use to achieve this will depend on site-specific characteristics.

- Once Lantana is established, only high intensity fire is able to significantly reduce its density over the medium term. There are potential impacts of intense fire on the rehabilitation of native plants including on the seed bank so it is not considered appropriate. Instead see P4 about low-intensity fire for prevention above.
- The use of splatter guns for Lantana control on a large scale has been proven highly effective.
- Some cases have shown the potential for weeds such as Lantana to maintain its Bell miner nesting benefits even after the plant is dead. This is because the dead canes still provide nesting habitat when the plants have been very dense. In such cases herbicide alone may not have the desired outcome of reducing Bell miner density so mechanical or fire in cooler months may be required as a follow up to the herbicide application.

Research, development and learning recommendations

R3(j): If there are sufficient funds beyond the causal investigations proposed in section 2, a second line of inquiry related to Lantana control could be run concurrently. Regardless of the link between Lantana and BMAD, Lantana has a significant economic and environmental impact on all land uses that should be minimised. This includes timber harvesting sites where the evidence clearly shows it impacts on the economic sustainability of timber harvesting by restricting regeneration of valuable timber. Note recommendations on lantana research will only be relevant where this invasive weed is prevalent; BMAD is known from areas south of where lantana has naturalised.

It is recommended that a decision tree for the selection of BMAD interventions be developed and then tested and refined using this line of inquiry.

Learning infrastructure

R3(k) Ongoing learning and improvement within the practitioner community should be supported. The following actions are provided for consideration:

- Provision be made to present the products of this review in an online setting for ready improvement as new evidence comes to light. This would include the causal model with evidence for individual relationships, case studies, and current recommended practice.
- Current recommended practices should be written up in more detail and placed into a separate document to assist sharing and offline use. This would include practical techniques such as:
    - how to confirm a BMAD site as opposed to other forms of eucalypt dieback,
    - how to select the most appropriate intervention for a site.
- The practitioner community should be provided with a means of submitting new and adding to existing case studies.
- An assessment should be conducted into the skills needed to properly diagnose and treat BMAD. This should inform the selection of a competency-based training program. The assessment should also inform the format of that training (i.e. online, face-to-face or

What are the costs of intervention? (Q4)

Recommendations: Question 4

R4(a): An economic analysis should be conducted of the costs and benefits of actively managing woody weed regrowth post-timber harvesting. Estimations should be made using the DPI aerial mapping as to the economic impact of BMAD on the value of timber harvesting areas in NSW State Forests over time.

R4(b): Costs of interventions used in the research proposed for Q3 should be monitored and published.

What impact does landholding size (small private versus large public lands) have on developing treatment options for BMAD? (Q5)

Recommendations: Question 5

R5(a): A viability assessment of different interventions based on the area that needs to be treated should be built into the intervention decision support discussed in R3(k).

4. The status of BMAD in NSW

4.1 Introduction

Understanding the current and potential future extent of BMAD in NSW is critical for raising awareness of the problem and allocating appropriate levels of resources for its management. This section of the review asks two related questions:

- **What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD? (Q6)**
- **What are the options for systematic monitoring of BMAD status and trend across NSW? (Q7)**

A combination of literature review, survey of practitioners and researchers, some GIS analysis and a specialist interview were used to collate data relevant to the two questions. A number of synthesis products have been developed to assist the development of conclusions and recommendations.

4.2 Method

Outline of the method

The Project Team followed the steps in Figure 6 to answer the two questions that form this part of the review. An explanation of each step follows.

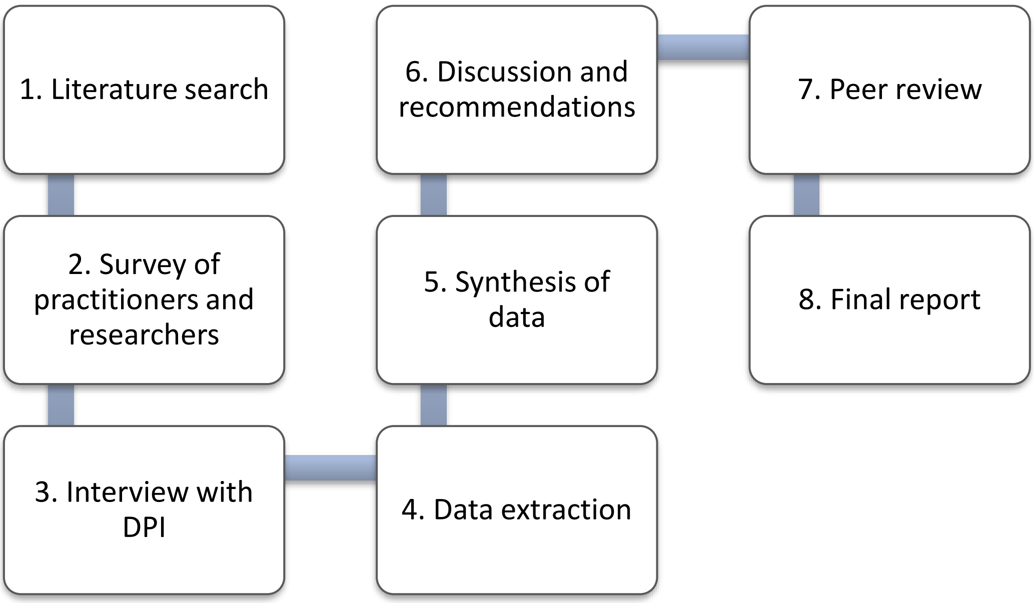

Figure 6. Steps in the method to review the evidence related to the status of BMAD in NSW.

Step 1: Literature search

The literature search undertaken to inform the two questions in this part of the review also informed other parts of the review such as a primary search for causal evidence (which was followed by secondary searches) and the identification of intervention case studies. For this reason, the search strings applied were broad. Searches were undertaken in English and were not restricted by publication date.

Bibliographic databases

The following bibliographic databases were searched for publications:

- Thomson Reuter's (formally ISI) Web of Science™ Core Collection
  http://apps.webofknowledge.com/

- Trove http://trove.nla.gov.au/

Search engines

An Internet search in Google Scholar was conducted. All records were retained for screening using the inclusion/exclusion criteria.

Search dates and strings

Table 10 provides the search strings used and dates of search.

Table 10. Search strings

Source	Search string	Date of search
Web of Science	"Bell miner*"	21 July 2016
Trove (book type only)	"Bell miner*"	23 July 2016
Google Scholar	"Bell miner*"	21 July 2016

* is the Boolean search modifier for a root word, stem, or truncation search.

Project Steering Committee literature

The Project Steering Committee contributed a collection of literature that they had collated.

Study inclusion criteria

After all of the search results were compiled and duplicate items removed, the remaining search results were screened and included/excluded according to the criteria outlined below for each question.

- What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD?
  - *Relevant location*: study must be from Australia.
  - *Relevant language*: study must be available in English.
  - *Relevant subject*: study must include discussion of one of the following:
    - mapping of BMAD
    - the location of BMAD identified via experimental sites
    - risk mapping.
- What are the options for systematic monitoring of BMAD status and trend across NSW?":
  - *Relevant location*: study must be from Australia.
  - *Relevant language*: study must be available in English.
  - *Relevant subject*: study must include discussion of monitoring methods related to BMAD (including but not limited to BM monitoring and dieback monitoring)

Step 2: Survey of researchers and practitioners

An online survey was developed and delivered via the Survey Monkey platform. The questions contained in the survey relating BMAD extend and monitoring are listed below.

Survey Q4. Please list any locations in NSW where you have observed known bell miner associated dieback.

For each of these locations the following information could be provided:

- Latitude
- Longitude
- BMAD impacts observed at this location (results in section 3 of this report)

Survey Q5. This question provided survey participants with a free text field to add more BMAD locations.

Step 3: Interview with NSW DPI's BMAD Mapping Team

The NSW DPI team that has recently conducted BMAD mapping were asked the following questions.

1. What area of NSW has your program mapped?
2. What was the method used to do the mapping and over what period what it done?
3. What are the costs of the method?
4. Did the method prove effective?
5. What products are available or will be available from the mapping?
6. In your opinion what additional mapping is needed in NSW?
7. How regularly should BMAD mapping be updated?
8. Would the same method need to be used to update the mapping over time?
9. What if any resources are available for additional BMAD mapping in NSW?
10. What coordination with other forms of monitoring (if any) would assist BMAD mapping in NSW?

Step 4: Data extraction

Data from literature

Table 11 documents how data was extracted from the literature.

Table 11. Data extraction from the literature.

What data was identified from the literature?	How was the data extracted?
Locations of BMAD in NSW	Locations known to contain BMAD were extracted from the literature. Where placenames were mentioned Google maps was used to gain latitude and longitude in decimal degrees. Multiple studies could be associated with the one location.
Potential risk factors for BMAD	Individual studies were assessed for the identification of factors associated with the presence of dense Bell miner colonies or psyllids infestations. Factors were tabled with the source evidence. An explanation as to why the factor is important was identified and documented.
BMAD monitoring and assessment methodology	Studies that discussed or tested particular methodologies for monitoring and assessing BMAD or parts of BMAD were identified.

Survey of practitioners and researchers

Responses to survey Questions 4 and 5 were collated into a table. Latitude and longitude (in decimal degrees) were identified from either the literature or by using Google maps.

DPI mapping team interview

No specific data extraction was undertaken on the NSW DPI interview responses; however the data did contribute to the discussion points and related recommendations in Section 5.

Step 5: Synthesis of data

BMAD extent map

GIS software was used to combine the following data sets into a single BMAD extent map for NSW:

- DPI aerial mapping (part of the state only)
- BMAD locations derived from the literature
- BMAD locations derived from the survey of practitioners and researchers.

Analysis of associations with BMAD locations

The data from NSW DPIs BMAD mapping program was compared with the site characteristics listed under dot point 2 to determine the extent to which the characteristics may be associated with BMAD.

1. Map showing the association of Bell miner density (from Australian Living Atlas data) with BMAD aerial mapping shown as Figure.
2. Frequency graphs of BMAD occurrence (DPI aerial mapping) compared to:
    a. Bell miner density
    b. vegetation type
    c. elevation
    d. topographic position index
    e. soil type
    f. annual rainfall
    g. mean temperature

Step 6: Discussion and recommendations

A set of conclusions was developed for each of the two review questions. Each of these included an assessment of the current evidence base, recommendations to strengthen the evidence base, and management implications.

Step 7: Peer review

The BMAD Project Steering Committee reviewed the draft report.

Step 8: Final report

Comments from the review process were assessed and relevant changes were made before delivering the final report to the BMAD Project Steering Committee.

4.3 Results and discussion

The results and discussion section is presented for each question. Question 6 is presented in the following two parts:

- What is the current extent of BMAD-affected land in NSW? (Q6a)
- What areas are currently at risk of BMAD? (Q6b)

4.3.1 What is the current extent of BMAD-affected land in NSW? (Q6a)

Data was collated from the following three sources:

1. DPI aerial BMAD mapping (no primary data provided in this report)
2. NSW BMAD locations identified in the literature found (Table 13)
3. NSW BMAD locations identified by respondents to the survey (Table 14).

DPI aerial BMAD mapping

Table 12 summarises the key discussion points from an interview conducted with Dr Angus Carnegie from the NSW DPI mapping team.

Table 12: Key points about the NSW DPI BMAD mapping program from an interview with Dr Angus Carnegie

Questions	Summary points from responses
What method was used to undertake the mapping? Over what period was the mapping done?	• Aerial survey from helicopter using digital aerial sketchmapping techniques (Carnegie et al. 2008), campaigns in September 2015, May and August 2016, April 2017. • Follow-up ground-truthing of a selection of aerial observations in February–April 2017.
What areas of NSW has your program mapped? Is there a map available to show this?	• Approximately 1,000,000 hectares has been flown. • Figure 6 provides the location of the mapped area in NSW.
Are there any initial figures available for BMAD extent within the areas mapped-to-date?	• Approximately 25,000 hectares of the 1,000,000 hectares mapped has BMAD. • This will be confirmed when the full results are released.
What are the approximate costs of the mapping method?	• Calculation from September 2015 flight: 11 hours flying, $20,000 helicopter hire (aerial observer costs not included), ~70,000 hectares flown = $0.28 per hectare. • A more complete cost per ha will be calculated from total area surveyed (by mid-to-late 2017).
Did the mapping method prove effective?	• Yes. Limited ground truthing has revealed that the aerial mapping is accurate.
What products are available, or will be available, from the mapping?	• Shapefiles of maps, including sketching (at various BMAD severity levels), flight lines, ground-truthing data. • Initial access (by mid-to-late 2017) is likely to be limited (e.g. to NSW government departments).

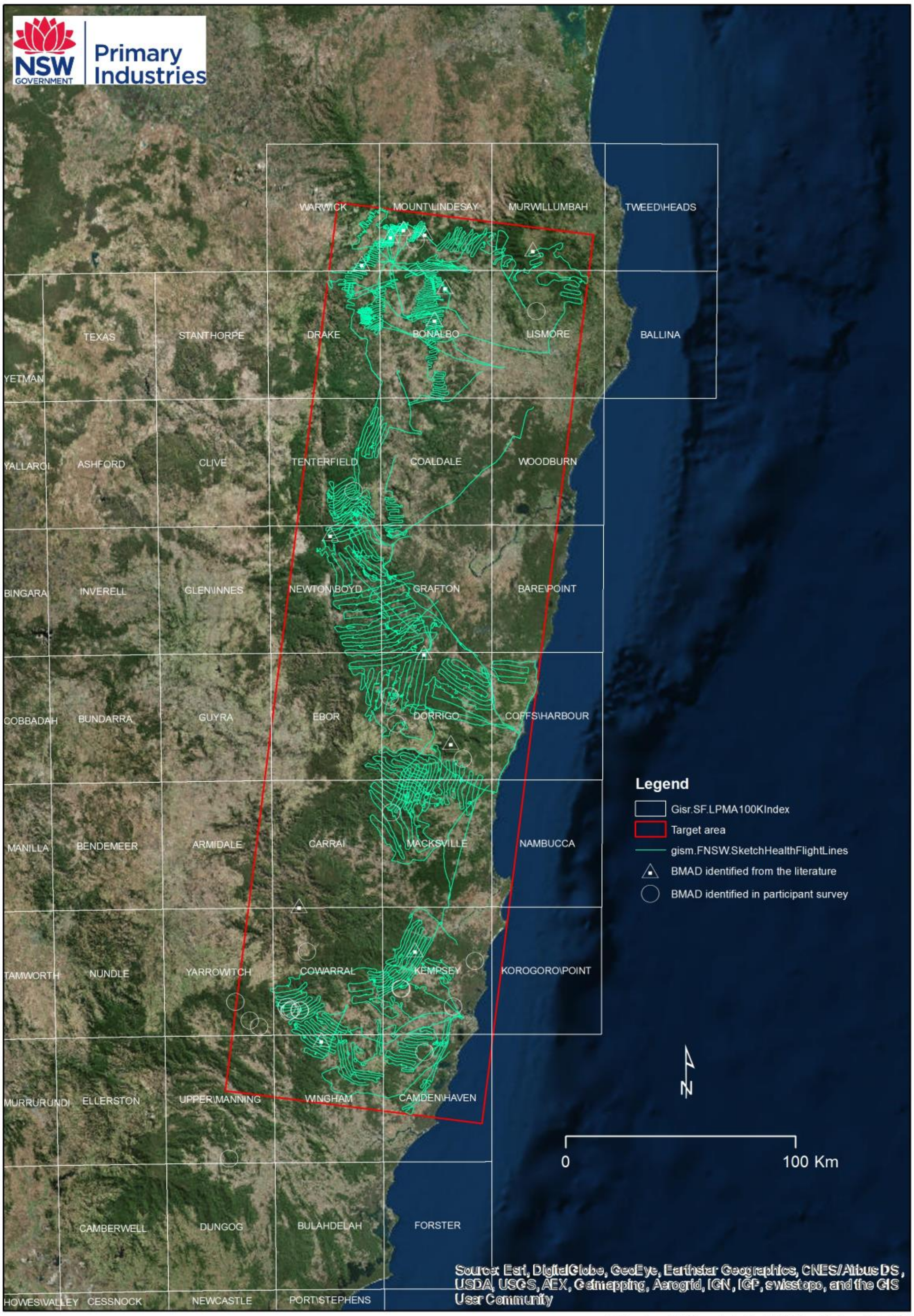

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Figure 6. Flight lines and area of BMAD mapping by NSW Department of Industry.

NSW BMAD locations identified in literature

Table 13 presents the locations of BMAD in NSW that are identified within literature found in the review. This data was used to develop a map of extent.

Table 13. BMAD locations identified in literature found.

Latitude	Longitude	Citation(s)
-28.46950	152.42183	Steinbauer et al., 2015
-28.36269	152.55023	Nageli et al., 2016
-28.35264	152.70299	Nageli et al., 2016; Nicholls, 2008
-28.41666	153.18333	Steinbauer et al., 2015
-28.33399	152.60662	Nageli et al., 2016
-28.56273	152.79199	Lambert et al., 2016; Nageli et al., 2016
-28.69011	152.74414	Stone, 2005
-29.53351	152.27396	Lambert et al., 2014; Steinbauer et al., 2015
-30.00061	152.69343	Moore, 1962
-30.35338	152.81469	Lambert et al., 2014
-31.16722	152.6501	Meek and others, 2008
-31.51774	152.2185	Moore, 1962
-30.99223	152.12197	Steinbauer et al., 2015
-33.11176	151.30352	(Coops et al., 2004, 2003, 2001; Kemmerer et al., 2008)
-33.29579	151.32459	Bird et al., 1974; Campbell and Moore, 1957; Moore, 1962
-33.15000	151.34166	(Stone, 1996; Stone et al., 2008, 2001)
-33.74093	151.13048	McDonald et al., 2002
-33.78333	150.96666	Stone and Simpson, 2006
-36.53555	149.89064	Smith, 1985
-36.83333	149.8999	Dare, 2010

NSW BMAD locations identified via survey

Thirty-three respondents provided location details for where they have observed BMAD. These locations are listed in Table 14.

Please note that this list does not include locations that were already identified from the literature. Multiple respondents identified some locations.

Table 14. BMAD locations identified by survey respondents.

Placename	Latitude	Longitude
Bellangry State Forest	-31.316901	152.585964
Glen Grant	-31.462069	151.933892
Herons Creek	-31.565674	152.690442

Placename	Latitude	Longitude
Oxley Highway, Gingers Creek	-31.399118	152.120135
Willi Willi National Park	-31.1687473	152.156353
Copeland Tops SCA	31.978611	151.79
Off Sauls Gully Road, Olney State Forest	33.106111	151.397778
Sawpit Road, Olney State Forest	33.123611	151.396944
Baerami Creek NSW	-32.514167	150.459444
Kedumba Valley Rd Wentworth Falls - along the trail within the national park	-33.776389	150.381667
Federation Pass Walking track/Golden Stairs, Katoomba - along flat section of track to Ruined Castle	-33.578333	150.283611
Bollanolla Nature Reserve	-31.3873613	152.8229331
Bostobrick	-30.2768009	152.5665785
Pine Creek State Forest6	-30.4144843	152.8687955
Vinegar Hill via Dundurrabin	-30.1695173	152.5383898
Horseshoe Rd Argents Hill	-30.6251652	152.5440948
Gibraltar Range NP	-29.36	152.38
just upstream of Bungonia Creek at Shoalhaven River confluence	-34.795789	150.038727
Jilliby State Conservation Area - Dooralong Valley	-33.148172	151.338944
Dairy Flat	-28.37873	152.66044
Kogo - Kipparra State Forest	-31.209444	152.923611
Bellangry/Bril Bril State Forest	-31.316944	152.583056
Cottan-Bimbang NP - Oxley Hwy - 5 sites	-31.385906	152.060915
Cottan-Bimbang NP - Oxley Hwy - 5 sites	-31.403807	152.071638
Cottan-Bimbang NP - Oxley Hwy - 5 sites	-31.401624	152.076482
Cottan-Bimbang NP - Oxley Hwy - 5 sites	-31.39443	152.084164
Cottan-Bimbang NP - Oxley Hwy - 5 sites	-31.400052	152.12076
Mummel Gulf NP - Dodds Trail	-31.43757	151.89093
Mummel Gulf NP - Dicks Hut Trail	-31.36455	151.8255
Riverview Road, Narooma	-36.209536	150.088703
Intersection of Golden Staircase track with Federal Pass track (Blue Mountains National Park)	-33.737203	150.283324
Jiggi Creek catchment specifically Davis Road sub catchment	-28.656389	153.198889
Prince Regents Glen	-33.734824	150.361623
Leura Falls Creek	-33.734115	150.319
Causeway Creek	-33.740776	150.28413

The above three sets of data were used to develop Figure 7.

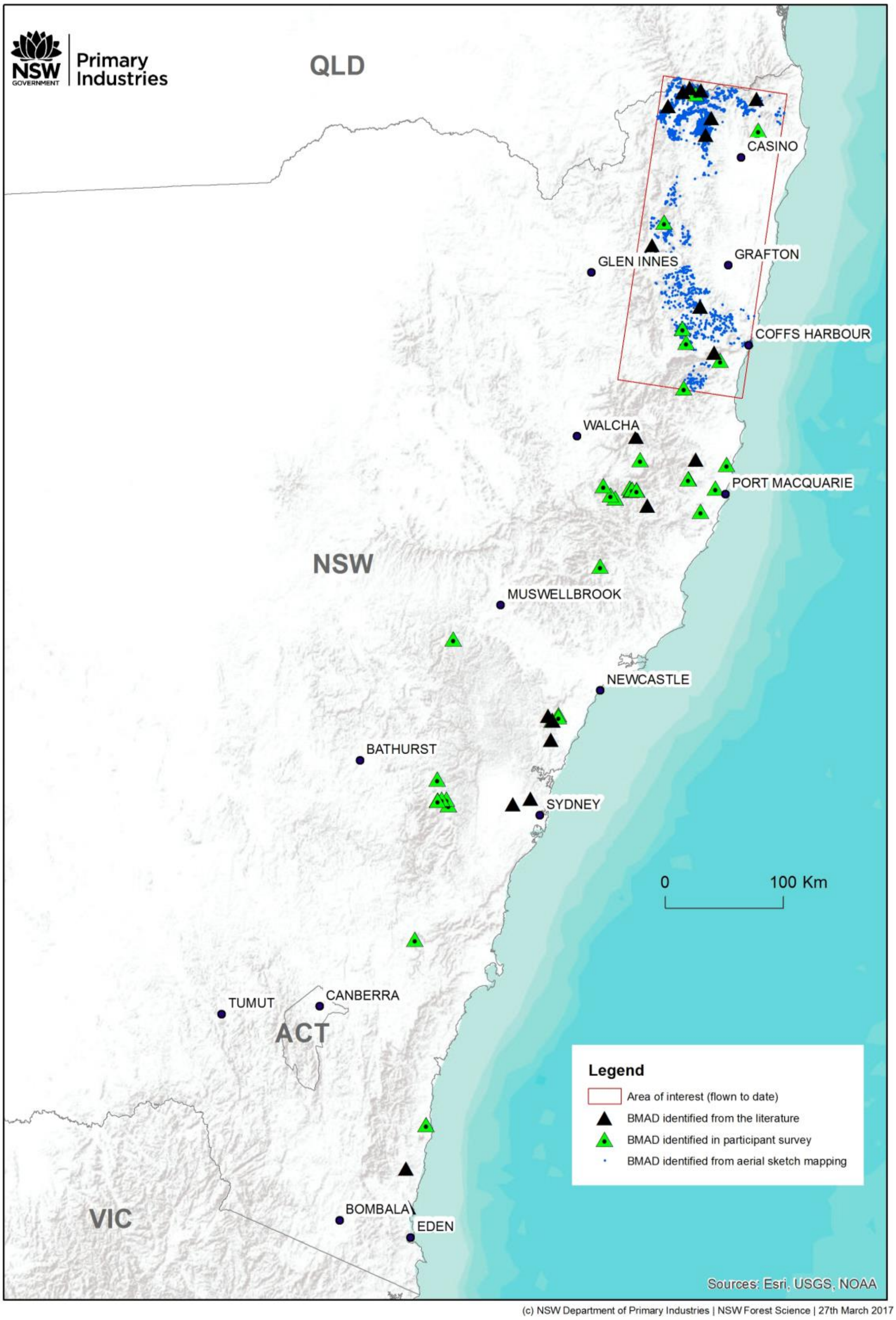

Figure 7. A map showing BMAD sites identified from aerial mapping, literature and survey responses.

There is now a reliable and comprehensive understanding of BMAD extent across the area mapped by the NSW DPI program, approximately 1,000,000ha of the potential BMAD area in NSW, however the remainder of susceptible land in NSW remains poorly mapped. Within the area mapped, approximately 25,000 hectares of BMAD has been identified. The only data available for the area outside the mapped area is from locations identified in literature and via the survey, which provides only some idea of the location of BMAD in the southern parts of NSW as opposed to its extent.

Completion of aerial mapping across NSW should be considered a priority for investment since understanding the scale of the problem is critical in raising awareness and gaining future investment for management.

4.3.2 What areas are currently at risk of BMAD? (Q6b)

Data was collated from the following sources to review this question:

1. Any literature containing BMAD risk maps.
2. Literature identifying variables associated with BMAD that may be useful risk indicators, and
3. An analysis of spatial data to identify associations with BMAD locations from the DPI mapping.

Literature containing BMAD risk mapping

No items were found that include BMAD risk or susceptibility mapping.

BMAD risk factors

These could include (but not be limited to) investigating the usefulness of using the pre-conditions listed in Table 15 below as risk indicators.

Table 15. Potential risk factors for the occurrence of BMAD.

Potential risk factor	Why is this important?	Source evidence
Lower elevations with wetter soil	Wetter areas are more likely to sustain the new growth and quantity of growth needed to sustain the psyllid population. It is also likely to be indicative of surface water availability for Bell miners.	(Haywood and Stone, 2011; Moore, 1962; Neave et al., 1996; Recher et al., 1991; Stone, 2005; Stone et al., 2008) Note that Stone 2005 did not find a significant correlation with soil wetness.
Higher soil fertility	Plants can only sustain flushes of leaves in good growing conditions.	(Stone, 2005)
Freshwater available nearby	A basic habitat requirement of Bell miners.	(McCulloch and Noelker, 1974; Neave et al., 1996)
Dense understorey	A dense understorey has a high correlation with Bell miner abundance as it has a significant impact on nestling success.	(Clarke and Heathcote, 1990; McDonald et al., 2002; StClair, 2010; Stone, 2005; Stone et al., 2008)
High psyllid abundance (note this may increase with the BM population and does not need to be a precursor)	A high concentration of food source is needed to sustain higher densities of Bell miners.	(Clarke and Schedvin, 1999; Dare et al., 2007; Stone et al., 2008)
Fe and B in leaves	Fe and B were associated with more severe crown damage.	(Nageli et al., 2016)
Absence of regrowth trees	An inability of a site to generate canopy closure creates conditions more likely to lead to dense understorey.	(Stone et al., 2008)

Potential risk factor	Why is this important?	Source evidence
Eucalypt species	Certain Eucalypt species seem more prone to psyllid infestations (e.g. grey ironbark). Non-eucalypts do not seem as prone.	(Smith, 1984; Stone et al., 2008, 1995)

Table 16 lists variables that have been reported to not differ significantly between BMAD and non-BMAD sites. Please note this does not necessarily mean this variable is not a risk factor in all locations.

Table 16. Factors that have shown not to be significant in determining BMAD presence.

Factor that was assessed but not found to be significant*	Source evidence
Soil drainage	(Stone, 2005)
Soil type	(Nageli et al., 2016)
N, P, and K values in leaves	(Nageli et al., 2016)
Zn, Na and N:K ratio in leaves	(Nageli et al., 2016)
Type of eucalypt community where Bell miners are located	(Pearce and Minchin, 2001)

Spatial data analysis to identify BMAD associations

The data from DPIs BMAD mapping program was overlayed with a variety of site characteristics to determine the extent to which the characteristics may be associated with BMAD. This was a preliminary analysis to provide some guidance for the selection of search terms that might be used for searches specific to individual causal relationships. These characteristics were:

1. Map showing the association of Bell miner density (from Australian Living Atlas data) with BMAD aerial mapping shown as Figure 8.
2. Frequency graphs of BMAD occurrence (DPI aerial mapping) versus:
    a. Bell miner density [data from Atlas of Living Australia (www.ala.org.au)] (Figure 9)
    b. Elevation (Figure 10)
    c. Vegetation type [data from Vegetation Information System (http://www.environment.nsw.gov.au/biobanking/vegtypedatabase.htm)] (Figure 11)
    d. Topographic position index (Figure 12)
    e. Soil type (Figure 13)
    f. Annual rainfall (Figure 14)
    g. Mean temperature (Figure 15).

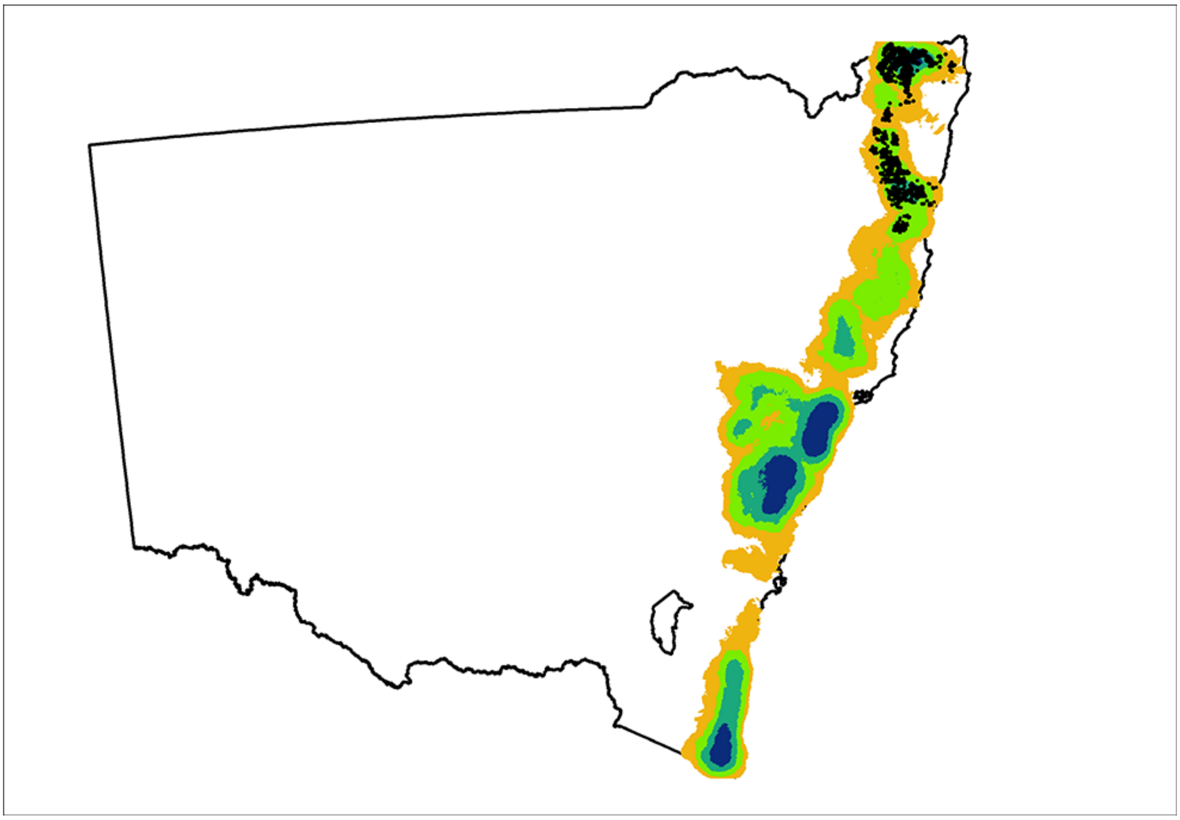

Figure 8. The association of Bell miner density with BMAD aerial mapping.

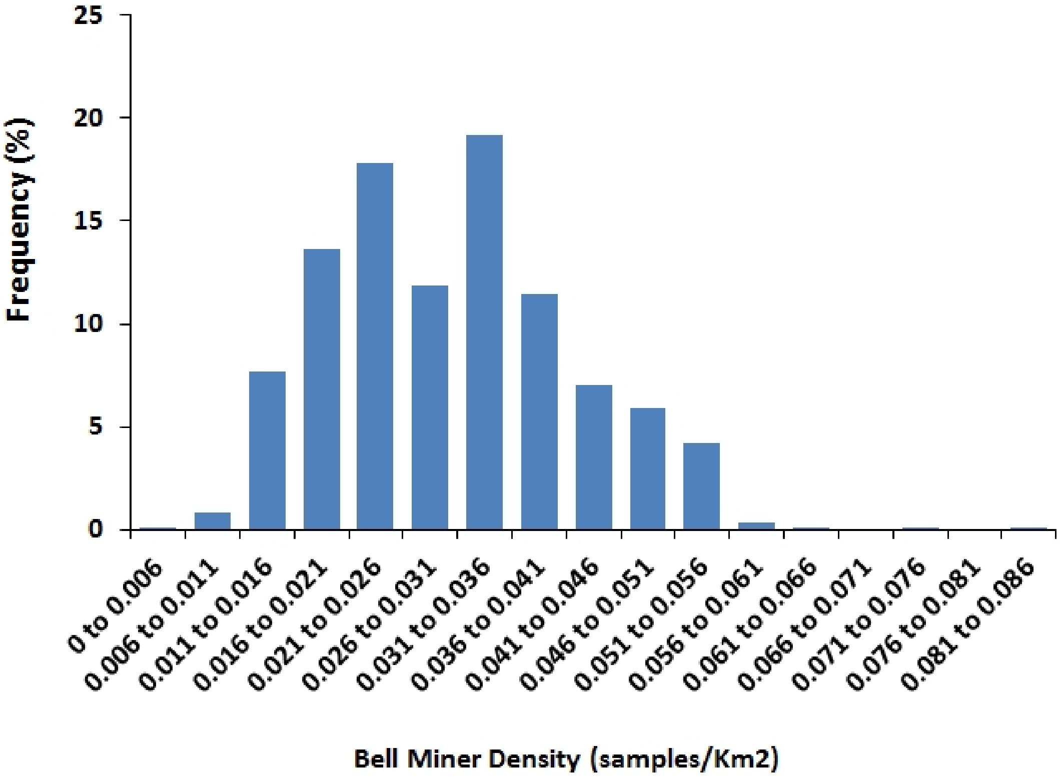

Figure 9. The percentage frequency of BMAD versus Bell miner density

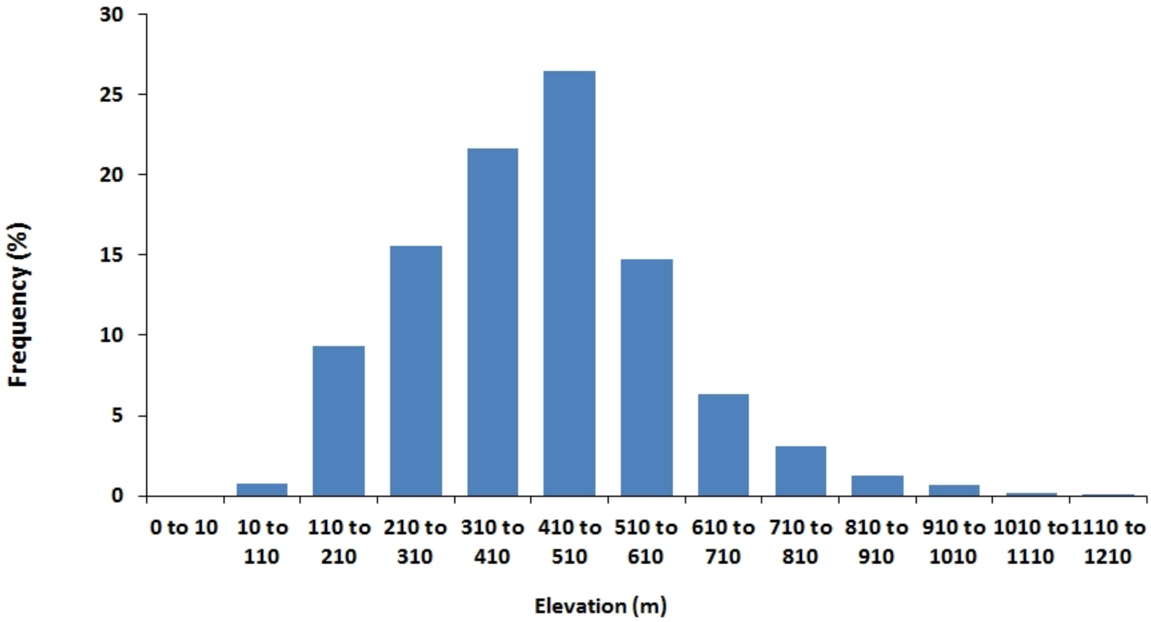

Figure 10. The percentage frequency of BMAD versus elevation.

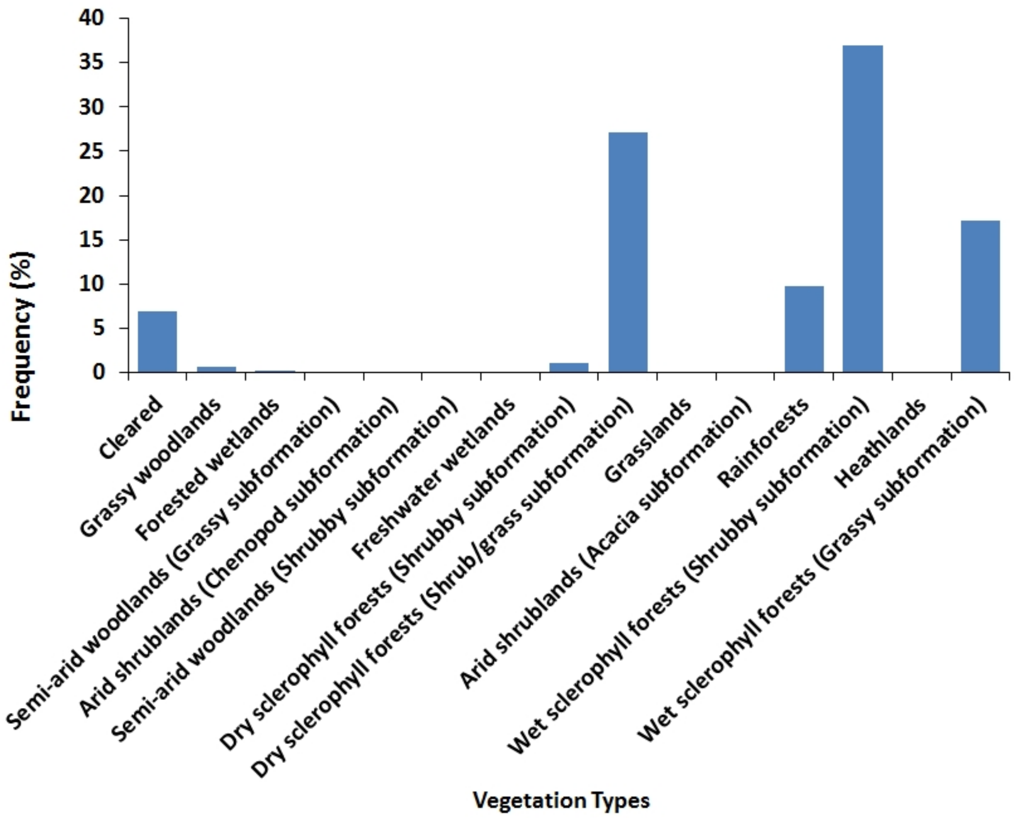

Figure 11. The percentage frequency of BMAD versus vegetation type.

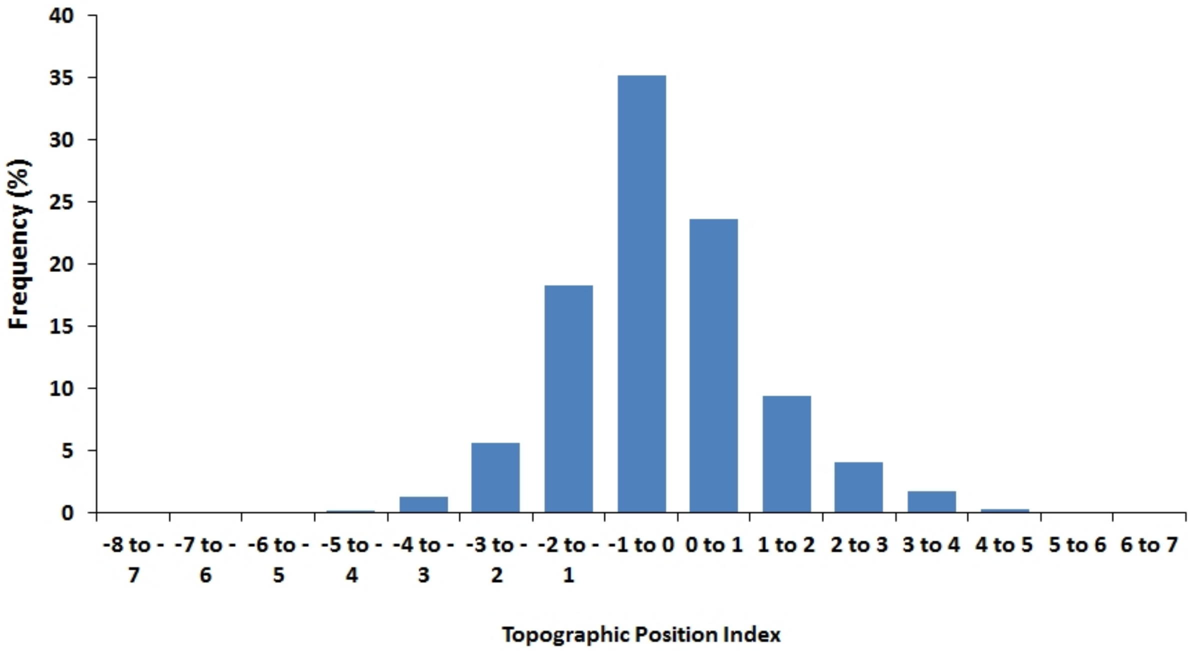

Figure 12. The percentage frequency of BMAD versus topographic position index.

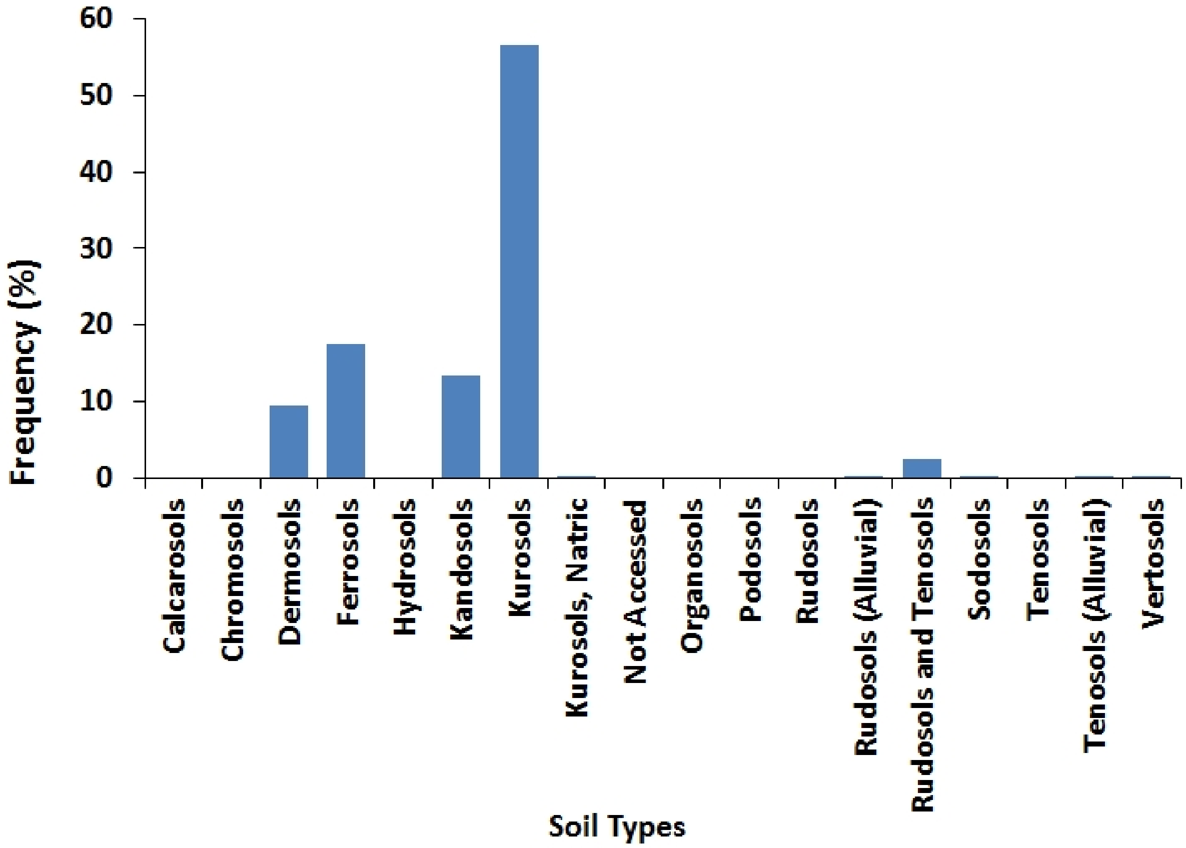

Figure 13. The percentage frequency of BMAD versus soil type.

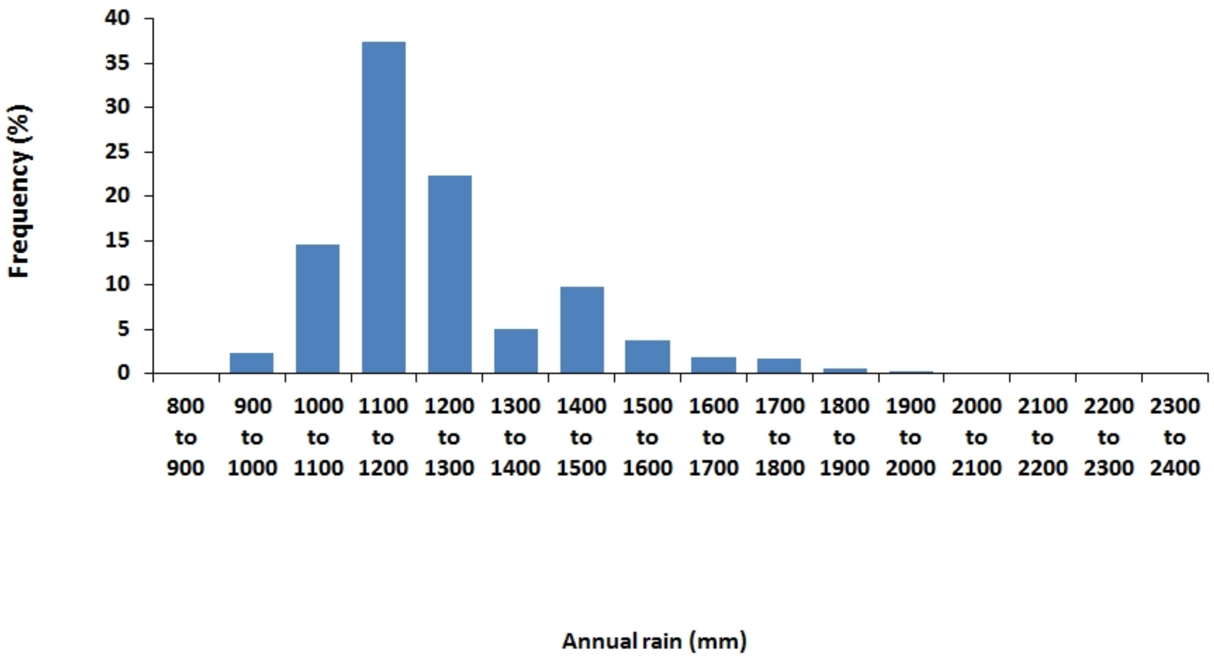

Figure 14. The percentage frequency of BMAD versus annual rainfall.

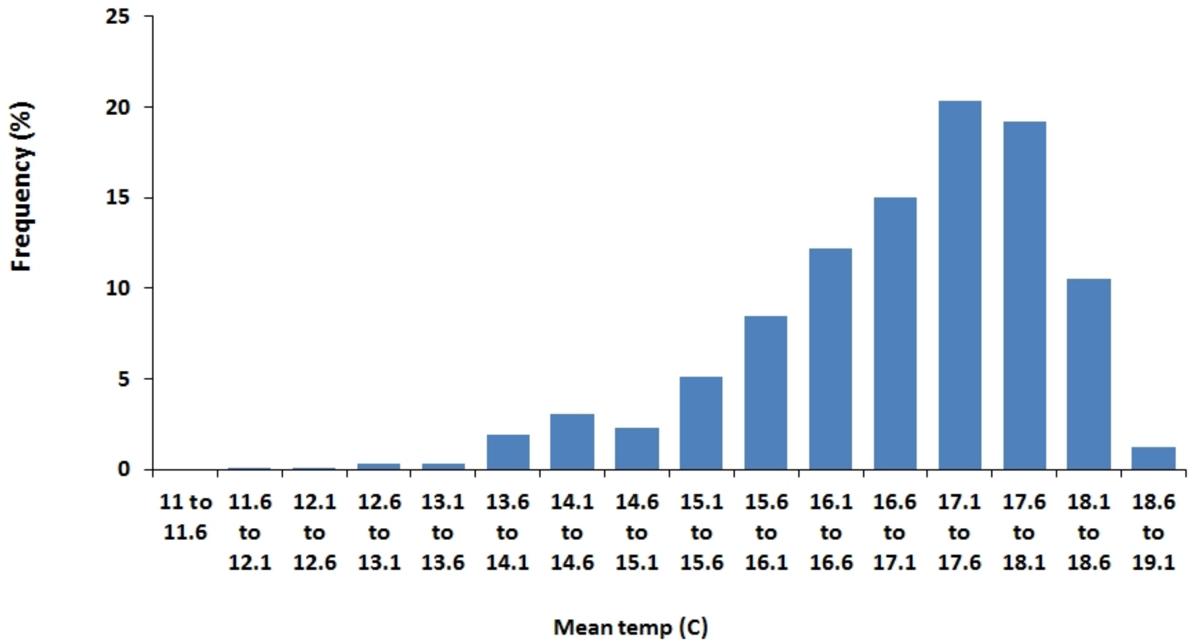

Figure 15. The percentage frequency of BMAD versus mean temperature.

No maps of BMAD risk or susceptibility for the state of NSW were identified in the searches. However, a risk modelling framework has been successfully developed and trialled for a particular site (Haywood and Stone, 2011). DoI Lands – Forest sciences is also currently conducting a remote sensing study of the north coast NSW across 6 million hectares of forest. One of the objectives of this project is to determine if BMAD can be mapped using Landsat & Sentinel imagery (Stone, pers. comms, 2017).

The existing DoI aerial mapping has provided a data set to not only assess the extent of current BMAD but also investigate ways of predicting the future potential spread of BMAD. The most useful management application of this information is in combination with the causal model (Section 2) to develop BMAD site risk assessment processes.

Based on the causal model, it is the potential for dense Bell miner colonies in combination with psyllid infestations that are important to predict. The following variables would appear to have value in forming a risk assessment:

1. Distance to local Bell miner colonies
2. Lower elevations, slopes and gullies; not ridges
3. Existing or potential for dense understorey/mid-storey
4. Vegetation type – particular eucalypt species known to be prone to psyllid infestations
5. Distance to freshwater

It should be noted that it is not a given that a BMAD risk map would be a useful tool for land managers. It may be that the variables needed for a risk assessment cannot be gathered at that scale. If some variables are available then a map may be possible that simply indicates where a site assessment is necessary.

4.3.3 What are the options for systematic monitoring of BMAD status and trend across NSW? (Q7)

The studies listed in Table 17 were identified during the literature searches as particularly relevant to the monitoring and assessment of BMAD. Most involve the testing of methodology such as remote sensing or comments on the value of particular methods. The review team does not suggest that this list is by any means comprehensive and only provides it here as a starting point to aid any future development of methodology.

Table 17. Studies found during literature searches that include discussion of methods useful for identifying BMAD.

Citation	Reference details
(Carnegie et al., 2008)	Carnegie, A.J., Cant, R.G., Eldridge, R.H., 2008. Forest health surveillance in New South Wales, Australia. Australian Forestry 71, 164–176.
(Clarke and Heathcote, 1988)	Clarke, M.F., Heathcote, C.F., 1988. Methods for sexing and aging the Bell miner Manorina melanophrys. Emu 88, 118–121.
(Coops et al., 2004)	Coops, N.C., Stone, C., Culvenor, D.S., Chisholm, L., 2004. Assessment of crown condition in eucalypt vegetation by remotely sensed optical indices. Journal of Environmental Quality 33, 956–964.
(Coops et al., 2003)	Coops, N.C., Stone, C., Culvenor, D.S., Chisholm, L.A., Merton, R.N., 2003. Chlorophyll content in eucalypt vegetation at the leaf and canopy scales as derived from high resolution spectral data. Tree Physiol. 23, 23–31.
(Coops et al., 2001)	Coops, N.C., Stone, C., Merton, R., Chisholm, L., 2001. Assessing eucalypt foliar health with field-based spectra and high spatial resolution hyperspectral imagery, in: Geoscience and Remote Sensing Symposium, 2001. IGARSS'01. IEEE 2001 International. IEEE, pp. 603–605.
(Cunningham et al., 2007)	Cunningham, S.C., Read, J., Baker, P.J., Mac Nally, R., 2007. Quantitative assessment of stand condition and its relationship to

Citation	Reference details
	physiological stress in stands of Eucalyptus camaldulensis (Myrtaceae). Aust. J. Bot. 55, 692–699.
(Horton et al., 2011)	Horton, B.M., Close, D.C., Wardlaw, T.J., Davidson, N.J., 2011. Crown condition assessment: an accurate, precise and efficient method with broad applicability to Eucalyptus. Austral Ecology 36, 709–721.
(Lambert and McDonald, 2014)	Lambert, K.T.A., McDonald, P.G., 2014. A low-cost, yet simple and highly repeatable system for acoustically surveying cryptic species. Austral Ecol. 39, 779–785. doi:10.1111/aec.12143
(Martin et al., 2001)	Martin, R.A.U., Burgman, M.A., Minchin, P.R., 2001. Spatial analysis of eucalypt dieback at Coranderrk, Australia. Appl. Veg. Sci. 4, 257–266.
(Stone et al., 2001)	Stone, C., Chisholm, L., Coops, N., 2001. Spectral reflectance characteristics of eucalypt foliage damaged by insects. Aust. J. Bot. 49, 687–698. doi:10.1071/BT00091
(Stone and Haywood, 2006)	Stone, C., Haywood, A., 2006. Assessing canopy health of native eucalypt forests. Ecological Management & Restoration 7, S24–S30. doi:10.1111/j.1442-8903.2006.00288.x
(Stone et al., 2003)	Stone, C., Wardlaw, T., Floyd, R., Carnegie, A., Wylie, R., De Little, D., 2003. Harmonisation of methods for the assessment and reporting of forest health in Australia—a starting point: A discussion paper prepared by a sub-committee of the Forest Research Working Group on Forest Health. Australian Forestry 66, 233–246
(Stone, 1999)	Stone, C., 1999. Assessment and monitoring of decline and dieback of forest eucalypts in relation to ecologically sustainable forest management: a review with a case study. Australian Forestry 62, 51–58.
(Stone and Coops, 2004)	Stone, C., Coops, N.C., 2004. Assessment and monitoring of damage from insects in Australian eucalypt forests and commercial plantations. Australian Journal of Entomology 43, 283–292.

In addition to the literature found, the questions and responses from the DPI mapping team interview listed in Table 18 are related to this question.

Table 18. Interview responses from the DPI BMAD mapping team related to Qu7.

Interview question	Summary of response
How regularly should BMAD mapping be updated?	• Ideally it would be done every 5 years.
Would the same method need to be used to update the mapping over time?	• NSW Forest Science is currently investigating the accuracy of freely-available remote sensing technology (Landsat, Sentinel) for BMAD mapping, based on the aerial surveys already undertaken. • If acceptably accurate, such analysis could be used to map BMAD into the future as well as retrospectively. • This work should provide results by mid-to-late 2017.
What if any resources are available for additional BMAD mapping in NSW?	• This depends on the results of the work to assess the use of remote sensing.

Interview question	Summary of response
	• If remote sensing is accurate enough to be used then completing the mapping for the state requires resources to analyse imagery and report results.
What coordination with other forms of monitoring (if any) would assist BMAD mapping in NSW?	• FCNSW, NPWS and citizen science all collect some BMAD/Bell miner data. • Collating this data and overlaying it onto remote mapping would be useful. • Standardising data collection and sharing processes would aid this.

4.4 Recommendations

What is the current extent of BMAD-affected land in NSW, and what areas are currently at risk of BMAD? (Q6)

Recommendations: Question 6
R6(a): Aerial mapping be completed for higher risk areas of the state. Existing mapping has shown high correlation with Bell miner density (regardless of causality) so this could be used as a guide for prioritising areas. **R6(b):** Provision to be made for online submission of on-ground sites where BMAD has been identified. This will aid with ground-truthing of aerial mapping. **R6(c):** Analysis be conducted on existing DPI BMAD mapping to identify the best risk indicators or preconditions for BMAD. Once this is done a BMAD risk map or site based assessment process should be developed.

What are the options for systematic monitoring of BMAD status and trend across NSW? (Q7)

Recommendations: Question 7
R7(a): Recommendations should be requested from the DoI mapping team regarding ongoing monitoring of BMAD across the state once the effectiveness of remote sensing mapping is known. This is likely to be in mid-late 2017.

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Appendix A: Synopsis and critical appraisal of studies that informed the BMAD causal model relationships

The following table provides a synopsis and critical appraisal of each study that measures one or more relationships in the BMAD causal model. Studies that discuss potential mechanisms of causal relationships but do not measure them (e.g. some bird behaviour studies) are not used to assess the certainty provided by the evidence base and are therefore not included.

Synopsis	Critical appraisal	
Abbott et al. 1993 Abbott et al. (1993) artificially defoliated regrowth *E. marginata* in Western Australia under various frequencies (percentage crown defoliated) and intensities (single or multiple defoliation events). After three years, multiple defoliations at low intensity had a greater impact than lower frequency defoliations at a higher intensity. Growth loss was a linear function of the severity of defoliation. A comparison with previous studies indicates that defoliation of mature trees has a greater impact on growth than defoliation of young, vigorously growing trees. They proposed that defoliation affected the production of carbohydrates by photosynthesis, and depleted reserves due to reallocation of carbohydrates to produce a new crown.	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Bamber and Humphreys 1965 Bamber and Humphreys (1965) investigated variation in starch (carbohydrate) levels in forest trees in a range of locations in NSW comparing defoliated and healthy trees. The trees examined included: artificially defoliated *Angophora costata* in Sydney (including a single defoliation event and repeated defoliation); fire-damaged *A. costata* in Sydney; several *Eucalyptus* species defoliated by phasmatid insects in the southern and central tablelands; *E. saligna* damaged by *Glycaspis* psyllids on the central coast. They also sampled trees that had known to be recently killed by repeated insect defoliation. Mean starch levels in control *A. costata* trees showed seasonal variations, declining during periods of flush growth and increasing during periods of relative dormancy. *Angophora costata* trees with a single manual defoliation event rapidly lost starch while they replaced their crowns, and returned to similar starch levels as undefoliated trees within 12 months, while trees with repeated defoliation rapidly lost starch initially, then more slowly, until reaching zero within 12 months. The authors postulated that the upsurge in starch content when trees had no leaves must have been a result of reallocation of resources from the roots. Starch in trees damaged by fire rapidly reduced and then gradually return to the same levels as un-burnt trees within 12 months.	**Study type**	Reference vs Control (2)
	Control sample units	5 (3)
	Impact/treatment sample units	5 (3)
	Potential for bias weighting	[pseudoreplication?]
	Potential for bias assessment	

Synopsis	Critical appraisal	
Eucalyptus tree severely defoliated by phasmatids had significantly lower sapwood starch compared to healthy trees. Dead trees sampled, including those that had recently died due to repeated phasmatid attack, had no starch in the sapwood; successive defoliation and crown replacement events had likely exhausted starch reserves with no replacement due to lack of photosynthetically active leaves. For *E. saligna* trees with no psyllid attack, starch levels rapidly declined after summer, reaching a low-point over winter before rapidly increasing in spring. Trees that had previous psyllid damage had significantly lower starch levels than healthy trees, but when psyllid left this site, starch levels rapidly rose after summer to the same levels as unaffected trees. A healthy site that had "new attack" by psyllids followed the same trend as healthy trees with a rapid decline in starch after summer, but starch levels did not return to the same high levels after winter as in healthy trees. The overall conclusion was that starch reserves are depleted during periods of regenerating following a severe defoliation event, and that repeated severe defoliation events can totally deplete starch reserves leading to mortality.		
Barry et a. 2011 Barry et al. (2011) defoliated saplings of *E. globulus* at 3 and 9 months under several resource treatments (adequate water and nitrogen, low water and low nitrogen, etc.) and measured the response at 18 months. Height, stem diameter and leaf area were not affected by defoliation under any of the resource treatments. Stem volume, bark volume and branch number increased for defoliated saplings. Above-ground biomass was greater.	**Study type**	Reference vs Control (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Clarke 1984b Clarke (1984b) monitored populations of Bell miners and Noisy Miners (*Manorina melanochephala*) that inhabited abutting territories in Bundoora, Victoria over a seventeen-month period. The Bell miner colony, which appeared to be divided into two groups (southern and northern), was initially co-inhabited by three other avian species, with all other avian species actively excluded by the Bell miners. A group of Noisy Miners invaded the southern Bell miner group over a six-day period, ultimately expelling the Bell miners. The Noisy Miners subsequently (and inexplicably) left the area, which was not re-colonised by Bell miners. Within two weeks the southern group area was colonised by 15 avian species, which foraged un-harassed. The most abundant initial colonisers were species that inhabit the same niche as Bell miners (mid-storey) and directly compete with Bell miners for food	**Study type**	Before vs After (no control) (2)
	Control sample units	0 (0)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	None; observational
	Potential for bias assessment	

Synopsis	Critical appraisal	
(e.g. Spotted Pardalote, White-naped honeyeater and Eastern Rosella, that feed on psyllid lerps). The rapid colonisation by other avian species, once Bell miners had been expelled, provides strong evidence for the ability of Bell miners to exclude other avian species from their territory.		
Clark and Dallwitz 1974	**Study type**	After impact (1)
Clark and Dallwitz (1974) monitored fluctuations in psyllids numbers on mature *E. blakelyi* in Canberra for seven years. The favourableness of the leaves as a source of food was the principal influence affecting *Glycaspis* spp. abundance; young leaves (4–8 weeks old) were more favourable than mature leaves, with old leaves not favourable at all. Moist conditions favoured psyllids. Dry conditions in the previous year favoured psyllids.	**Control sample units**	0 (0)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Clarke and Heathcote 1990	**Study type**	Observational
Clarke and Heathcote (1990) monitored Bell miner dispersal, survival and demography in a dry, layered woodland lining a gully near Melbourne Victoria, over a six-year period. Nestlings had a high mortality rate (70%) prior to the mean dispersal age (8 months), due to predation. Dispersal was generally no farther than 1 km from the colony, and always over non-suitable/occupied habitat, with females being primarily the dispersal sex. They noted that “habitat requirements appear to include thick understorey vegetation for nesting and a healthy eucalypt overstorey in which to feed”, and that such habitats are patchily distributed with minimal marginal habitats. However, no conclusive evidence provided by this study to support this relationship.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	
Clarke and Fitz-Gerald 1994	**Study type**	Observational
Clarke and Fitz-Gerald (1994) monitored the behaviour of four Bell miner colonies in Bundoora, Victoria, over a 4-year period, including foraging range, colony territory, and opportunistic observations of intraspecific aggression. Bell miners occurred in geographically discrete colonies, which generally composed several breeding pairs with overlapping ranges with non-breeding offspring and immigrants. All individuals aggressively defended a colony’s territory from interspecific intruders throughout the year, with males more prominent than females. “Other avian species were almost totally excluded from areas defended by colonies of Bell miners”. Thirty-seven avian species were observed entering Bell miner colonies and all but four were expelled; the only birds that weren’t excluded were understorey species, which rarely overlap with Bell miners’ territory. The authors	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
surmised that the resources being defended by Bell miners may have been the predominant food source (lerp psyllids) and dense understorey for nesting. Furthermore, local movement by colonies may be a response to reducing canopy quality, allowing for canopies to recover from insect attack; habitat alteration by humans may restrict such local migration, such that insect attack continues eventually killing trees.		
Clarke and Schedvin 1999	**Study type**	BACI (4)
Clarke and Schedvin (1999) removed (culled) Bell miners from a dieback-affected site near Healesville, Victoria, and monitored avian diversity and abundance, psyllid (*Glycaspis* sp.) abundance, and tree health over the following two years, in comparison to two 'control' sites; one with Bell miners and dieback and one without Bell miners or dieback. Prior to the cull, the control site with no Bell miners had significantly greater avian diversity than either of the Bell miner sites, but both Bell miner sites had significantly greater avian abundance. Prior to the cull, the two sites with Bell miners (and dieback) had psyllids present, while the site with no Bell miners had no psyllids. Following the cull, there was a large influx of other avian species, especially those that fed on lerp psyllids (e.g. white-naped honeyeater, crimson rosella, spotted pardalote), with the number trebling within 12 days, and a subsequent crash in psyllid numbers. Total avian abundance soon returned to pre-cull levels, seemingly because the psyllids present could not support the large influx of insectivorous birds. Bell miners eventually re-colonised the site, but at lower abundance than pre-cull levels, followed by an increase in psyllids. Following the Bell miner cull, there was a dramatic decrease in psyllid abundance, and this compared to an increase in psyllid abundance at the 'control' site with Bell miners still present. Psyllid abundance eventually recovered at the cull site, after a small colony of Bell miners re-established at the site. Conversely, psyllid abundance at the 'control' site with Bell miners later decreased following the abandonment of the site by the Bell miners. Thus, the abundance of psyllids was strongly associated with the presence of Bell miners. There was no significant improvement in tree health 28 months after the removal of Bell miners, although the continued decline in tree health was lower at the cull site compared to the Bell miner site. Bell miners had been present in the reserve for over 30 years, and the authors postulated that trees may have already been too severely damaged to recover. Bell miners eventually abandoned the Bell miner control site as tree health declined and many trees died, shifting 100 m to a habitat with healthier trees. The root rot pathogen *Phytophthora cinnamomic* was present at both dieback sites.	**Control sample units**	1 (2)
	Impact/treatment sample units	1(0)
	Potential for bias weighting	
	Potential for bias assessment	
Cummings et al. 2007	**Study type**	Reference vs Impact (2)
Cummings et al. (2007) compared tree thinning (and clearfall) and weed control in a mature *E. grandis* plantation in northern NSW to monitor regeneration following a disturbance event to investigate barriers	**Control sample units**	1 (2)

Synopsis	Critical appraisal	
that restrict natural regeneration in such plantation sites. Trees were either heavily thinned or all trees removed (clearfall), with no tree removal as the control. Lantana was initially removed from all treatments, including the control, then either left to regenerate (no weed control) or with annual lantana removal (weed control). Retained canopy cover (%) was used as a covariate, and understorey vegetation composition and structure assessed for 15 months. Thinning and weed control increased regeneration of native species overall, but species richness and density of native shrubs and understorey trees was greater under a closed canopy (70% canopy cover) compared to an open canopy (30% canopy cover). Competition from lantana (weed removal) was more important in successful regeneration of native species than competition (canopy cover) from the overstorey *E. grandis* (Cummings et al., 2007). In contrast, lantana was favoured by reduced canopy cover, with greater lantana cover in areas with greater initial canopy removal. Thus, while thinning of the canopy by tree removal promoted lantana density in the understorey, tree removal plus lantana removal promoted regeneration of native shrubs and trees in the understorey.	**Impact/treatment sample units**	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Dare et al. 2007 Dare et al. (2007) monitored the abundance of Bell miners and other avian species for seven months at two sites that had recently been invaded by Bell miners in Bundoora, Victoria. Aggressive territorial behaviour by Bell miners was observed soon after invasion, but ultimately only a handful of Bell miners successfully occupied the two sites during the study period, thus confounding the study and any conclusions from it. At one site, there was a clear effect of the 'tink' calls of Bell miners, with significantly lower abundance and species richness of other avian species when Bell miners were recorded giving their 'tink' calls compared to days when they were silent. At the second site, abundance and species richness of other bird species was lower in the presence of Bell miners compared to the control site with no Bell miners; the first site had too few Bell miners for there to be an effect. The abundance and diversity of other avian species was negatively impacted by Bell miners making 'tink' calls. Bell miners moved from a site with no understorey or mid-storey to sites with a dense understorey. These new sites did not have elevated levels of psyllids compared to surrounding areas with no Bell miners, and there were no significant changes in psyllid abundance after colonisation.	**Study type**	Reference vs Impact (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	Only 7-month study; very few Bell Birds (<5)
	Potential for bias assessment	0.5
Dare 2010 (Chapter 5) Dare (2010) [Chapter 5] monitored the abundance of predators and parasites in a BMAD site at Merimbula, southern NSW, prior to and following removal of bell miners to investigate the theory that bell miners interfere with the efficacy of other avian insect predators resulting in an increase in psyllids. Bell miners were culled from one property, while the birds were retained at a second nearby property.	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)

Synopsis	Critical appraisal	
The sites were re-assessed less than 12 months after bird removal. Tree health was not significantly different between treated and untreated sites, nor was there a difference in insect predators nor psyllid numbers. Note the relatively short time-frame, and as much of this was over winter, may not have been enough time for psyllid generations to noticeably expand. Note that Hastings (2012) assessed the same sites in 2011 and found a significant difference in tree health.	**Potential for bias weighting**	Short time-frame (<12 months), and bird-free mostly over winter period (not ideal time for insect expansion).
	Potential for bias assessment	0.50
Debuse & Lewis 2014 Debuse and Lewis (2014) examined long-term (1959 to 2007) patterns of lantana recruitment in dry eucalypt forest in Bauple State Forest, south eastern Queensland, under three fire frequencies/regimes: repeated annual burn, repeated triennial burn and long unburnt. The forest was dominated by spotted gum (*Corymbia citriodora* ssp. *variegata*), and experienced commercial logging and thinning in 1972–1974, with three height classes of lantana assessed (regeneration, young and mature plants). In the pre-logging period (1959–1972), annual burning significantly reduced total lantana abundance, reducing the density of lantana three-fold and supressing population growth. In contrast, in the long-unburnt forest total lantana density increased almost 500% over the same period (pre-logging). Similarly, the density of regenerating lantana decreased over time in the annually burnt forest but increased in the unburnt forest. Following logging, lantana densities continued to decline in the annual burn treatment, and continued to increase in the unburnt forest before rapidly declining after 1993. Lantana density can change over time under different fire regimes and disturbance (logging) events, but has the potential to significantly increase in density following invasion. Over the long-term, frequent fire can control lantana in dry eucalypt forest, and conversely, lack of fire can result in increased lantana in the understorey. In this case, lack of disturbance was associated with increased lantana invasion.	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	0
Duggin and Gentle 1998 Duggin and Gentle (1998) conducted three experiments in Oxley Wild Rivers National Park in north Queensland using varying intensities of fire, overstorey damage (biomass removal) and nutrient addition as disturbance events to monitor the effect on lantana invasion. Lantana seed were planted following treatments and monitored for 27 months. All three treatments significantly increased germination, survival, growth (biomass) and reproductive success of lantana compared to the control, with a differential increase in the effect with increasing intensity of the treatment. High intensity wildfire and complete biomass removal (including overstorey canopy) resulting in canopy gaps had the greatest effect on lantana invasion. These disturbance events increased resource availability, particularly light, which allowed increased site occupation by lantana. The addition of nutrients following disturbance	**Study type**	Gradient response model (3)
	Control sample units	n/a
	Impact/treatment sample units	2 (0)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
provided a minor but additive effect on lantana. Thus, disturbance events that reduce canopy density and/or produce canopy gaps significantly increase the invasion potential of lantana, increasing the density of the lantana understorey.		
Eyles et al. 2009	**Study type**	Reference vs Control (2)
Eyles et al. (2009) established a field experiment to examine the morphological and eco-physiological effects of artificial defoliation (40% leaf removal) on growth and biomass allocation of 8-month *E. globulus* saplings under different water and nutrient regimes (low and adequate) in Tasmania. Defoliation of *E. globulus* grown under a supply of adequate water and nutrients, or with a limited supply or water or nutrients (but not both), were able to compensate for a 40% loss in foliage within 5 months. Saplings grown under limited water *and* limited nutrients were significantly impacted by 40% defoliation. Defoliated saplings had a lower stem starch pool than undefoliated saplings. Trees under adequate conditions, or low water or low nutrients, were able to compensate for foliage loss by a range of physiological mechanisms, including reduced biomass allocation to coarse roots, mobilisation of carbohydrate reserves and robust internal N dynamics.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Fensham et al. 1994	**Study type**	Reference vs Impact (2)
Fensham et al. (1994) conducted transects through dry rainforest and savanna woodland in Forty Mile Scrub National Park, north Queensland, comparing areas long-invaded and heavily infested with lantana (>5000 plants per ha) into newly invaded and lightly infested areas (<1000 plants per ha). In the dry rainforest, lantana density was negatively correlated ($r^2 = 0.183$, $P < 0.001$) with overstorey (trees >4 m in height) canopy density, with >5000 individuals of lantana per ha in open (median 35% cover) overstorey canopy sites compared to <1000 individuals in dense (median 50% cover) overstorey canopy sites. In contrast, the difference in canopy density at heavily lantana infested sites (>5000 lantana plants per ha, canopy density mean 45%) and lightly infested sites (<1000 lantana plants per ha, canopy density median 30%) was not significant, although canopy density was greater at sites with heavy lantana infestation. Fensham et al. (1994) proposed that feral pig damage kills trees leading to an open overstorey canopy—and then increased lantana density; however, I don't believe the data presented for this was equivocal (e.g. they mention wildfires had "incinerated" the site on several occasions). So, although the agent of the thinning canopy was not clear, lantana density was significantly greater in dry rainforest stands with a sparse overstorey canopy compared to stands with a dense overstorey canopy. This trend was reversed in the savanna woodland though. Long-invaded lantana sites have a significantly greater understorey density than newly invaded sites.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
Gentle and Duggin 1997 Gentle and Duggin (1997) conducted a field experiment in Oxley Wild Rivers National Park, north-eastern NSW, by simulating disturbance similar to fire and/or cattle grazing leading to gaps in the dry rainforest-open forest ecotone and monitored its impact on "lantana invasion". Lantana seed was planted back into plots following treatment and monitored for 1.5. years. Disturbance mimicking fire (burning all vegetation up to 2.5 m in height) and grazing (all litter and above ground biomass removed) significantly ($P < 0.05$) increased survival and growth (biomass) of lantana compared to the control (no disturbance), with canopy removal having the greatest effect (= increased lantana growth and site occupation). Thus, activities that remove the canopy significantly increase the survival, growth and site occupation of lantana. As lantana invades these suitable sites, the overall density of the understorey increases compared to less-suitable sites.	**Study type**	Reference vs. Impact (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	0
Gentle & Duggin 1998 *In progress.*	**Study type**	
	Control sample units	
	Impact/treatment sample units	
	Potential for bias weighting	
	Potential for bias assessment	
Gooden et al. 2009b Gooden et al. (2009b) assessed plant species abundance, richness and density in comparison to severity of lantana invasion (percentage lantana cover) across fifty-three sites in North Coast Wet Sclerophyll Forest along the south-east coast ranges of NSW. Each site was assigned to one of three lantana invasion categories: non-invaded (0–5% cover), moderately invaded (6–50% cover) and heavily invaded (>51% cover). Vegetation composition (of ferns, herbs, shrubs, trees and vines) was surveyed at each site, including abundance (percentage foliage cover), species density (number of individual plants), species richness (total species recorded) and whether the species was native or exotic. Native species richness, across all growth forms, declined significantly with increasing lantana invasion. The rate of species decline was greater for shrub and tree species, indicating a shift to dense lantana-dominated understorey. Thus, as lantana invasion intensifies, the subsequent loss of shrub and tree species can result in an increase in understorey density dominated by lantana.	**Study type**	Gradient response model (3)
	Control sample units	19 (3)
	Impact/treatment sample units	34 (3)
	Potential for bias weighting	nil
	Potential for bias assessment	0

<table>
<tr><th>Synopsis</th><th colspan="2">Critical appraisal</th></tr>
<tr><td rowspan="5">Gooden et al. 2009a
Gooden et al. (2009a) assessed species richness and composition in Minnamurra Rainforest Reserve in south-east NSW comparing sites that had (1) been invaded by lantana (>50% lantana cover), (2) managed for lantana (dense lantana removed, and now <20% cover), (3) non-invaded (<5% lantana cover, not managed). The average lantana cover at the site prior to control activities ranged from 50% to 100%. Sites were assessed six years after management activities, which included removal of lantana by manual and chemical methods. Invasion by lantana significantly reduced species richness and composition. Management of lantana resulted in a return in the native vegetation community, but that follow-up control was necessary to stop re-invasion of lantana.</td><td>Study type</td><td>Gradient response (3)</td></tr>
<tr><td>Control sample units</td><td>1 (2)</td></tr>
<tr><td>Impact/treatment sample units</td><td>1 (0)</td></tr>
<tr><td>Potential for bias weighting</td><td></td></tr>
<tr><td>Potential for bias assessment</td><td></td></tr>
<tr><td rowspan="5">Kavanagh and Stanton 2003
Kavanagh and Stanton (2003) assessed the impact of intensive logging (where no mature trees were retained), compared to unlogged forest, on recovery of bird populations over time near Eden, southern NSW. Thirteen (13) years after logging there was greater bird abundance, and more bird species, in the unlogged coupes compared to the logged coupes, i.e. an immediate impact of logging on bird populations. After 22 years, however, there was no significant difference in bird abundance or species abundance between logged and unlogged, but a significant difference for some bird species. That is, at a community level, the bird population had generally recovered to pre-logged levels after 22 years. But this was not the case for all bird species: some species became less abundant 4, 13 and 22 years following logging, while other species became more abundant. Bell miners, for example, were significantly more abundant in logged coupes 22 years following logging compared to the unlogged coupes, especially in moist forest types at the heads of gullies.</td><td>Study type</td><td>Reference vs Impact (2)</td></tr>
<tr><td>Control sample units</td><td>1 (2)</td></tr>
<tr><td>Impact/treatment sample units</td><td>1 (0)</td></tr>
<tr><td>Potential for bias weighting</td><td>Logging resulted in greater Bell miner abundance, but didn’t hold for all coupes (“Bell miners increase greatly in some logged coupes”). Furthermore, high Bell miner numbers were seen 22 years after logging, when regeneration was now tall trees (i.e. no longer dense understorey).</td></tr>
<tr><td>Potential for bias assessment</td><td></td></tr>
<tr><td rowspan="3">Kavanagh and Stanton 2005
Kavanagh and Stanton (2005) analysed a large dataset that consisted of records of 227 vertebrate species across 487 forested sites in north-eastern NSW — which were stratified by broad forest type, logging history/intensity and elevation — based on data from Environmental Impact Statements (York et al. 1991). They found that some species were significantly disadvantaged by intensive logging,</td><td>Study type</td><td>Reference vs Impact (2)</td></tr>
<tr><td>Control sample units</td><td>218 (3)</td></tr>
<tr><td>Impact/treatment sample units</td><td>164+105 (3)</td></tr>
</table>

Synopsis	Critical appraisal	
including the Common Brushtail Possum (which are dependent on large old trees) and Rufous Bettong (which were likely disadvantaged by the increase in stem density following logging), while other species were favoured by intensive logging, including Lewin's Honeyeater (which prefer multi-layered moist forests), and Bell miners. They concluded that intensive logging greatly reduces the amount of forest canopy, and after an initial period of sparse understorey, results in a very dense understorey, then eventually a dense mid-canopy. Bell miners were among the species most advantaged by intensive logging, with significantly greater abundance in intensively logged forest compared to unlogged forest across 46 sites. However, the study did not identify at which stage of understorey regeneration following logging Bell miners preferred.	**Potential for bias weighting**	Logging increases Bell miner abundance, but dense understorey not identified as causal mechanism.
	Potential for bias assessment	
Kemmerer et al. 2008 Kemmerer et al. (2008) assessed Bell miner density to investigate the impact on the relative abundance and richness of other avian species, by assessing relative abundance of Bell miners over a 16-month period in Olney SF, central NSW, in an area known to have high species richness and Bell miners. The site was a moist eucalypt forest with a dense understorey of lantana and native sub-tropical shrubs. Eighty-nine (89) species of birds were recorded — indicating a high species richness in the forest — but Bell miners made up the majority (73%) of birds counted. Bell miner densities were also high; up to 40 birds/ha. Although there was a lot of variation in bird counts within and between plots, there was a significant (*P* < 0.0001) linear and negative relationship between relative Bell miner density and both species richness and abundance of other avian species. An analysis of data from a previous study (Webster 1995) also revealed a decline in species richness and abundance with increasing Bell miner density. This study showed that "when Bell miners are present, they dominate the avian community", resulting in a significant reduction in richness and abundance of other avian species.	**Study type**	Gradient response (3)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Lambert et al. 2014 Lambert et al. (2014) compared arthropod abundance and diversity between trees within a Bell miner colony and trees outside the colony at two sites in northern NSW, characterised by wet sclerophyll forests and dense lantana understorey. Two trees (Bell miner and control) from each site were fogged with insecticide and insects collected. A wide range of insects from 13 Orders and various feeding guilds (e.g. predators, parasites, leaf chewers, sap suckers, ants) were collected. Overall, the abundance of insects was greater at Bell miner sites (n = 181) compared to non-Bell miner sites (n = 67), but this difference was not statistically significant. This could be due to the small sample size (two trees each), and the authors discuss why they believe this is not the case.	**Study type**	Reference vs Impact (2)
	Control sample units	2 (3)
	Impact/treatment sample units	2 (2)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
Lambert 2015 (Chapter 5) Lambert (2015) investigated the effect of lantana control (chemical) on soil nutrient pools, bell miner density and canopy health at four BMAD sites in NSW, comparing sites treated for lantana and those with dense lantana. Two years' post treatment, there were not significant differences in soil nutrient pools, bell miner density or canopy health. Bell miners did not relocate from lantana controlled sites. All sites experienced below average rainfall, and this affected tree health. Chemical control of lantana did not remove canes, and this may not have altered the vegetation structure enough to alter bell miner behaviour (nesting sites).	**Study type**	Reference vs Impact (2)
	Control sample units	4 (3)
	Impact/treatment sample units	4 (3)
	Potential for bias weighting	
	Potential for bias assessment	
Lambert et al. 2016 Lambert et al. (2016) assessed the incidence of Bell miners and plant species abundance (both native and exotic species) in the understorey, mid-storey and canopy, in two forests (Creeks Bend and Toonumbar National Park) in northern NSW where dense lantana understorey had been physically removed by Somerville et al. (2011) over a 7-year period. They compared the effects of lantana removal to an untreated forest in Toonumbar National Park. Regeneration of native understorey, mid-storey and canopy species replaced the lantana, but this occurred at different rates and intensity between the two forests. Bell miners vacated one site (Creeks Bend), but not the other (Toonumbar National Park), and this difference in effect of lantana removal was believed to be associated with differences in stand structure between the two forests following regeneration after lantana removal. Following lantana control, Bell miners vacated forests where regeneration resulted in a sparse understorey, but a dense mid-storey and relatively dense canopy (Creeks Bend), but remained in Toonumba National Park, where regeneration resulted in a dense understorey, but sparse mid-storey and canopy. Bell miners were strongly associated with a dense native or exotic understorey.	**Study type**	Reference vs Impact (2)
	Control sample units	1 (2)
	Impact/treatment sample units	2 (2)
	Potential for bias weighting	nil
	Potential for bias assessment	
Landsberg and Wylie 1983 Landsberg and Wylie (1983) compared water stress, foliar nutrient concentrations and damage by foliar insects in dieback and matched healthy trees in rural south-eastern Queensland. A wide range of insects were recorded, including leaf chewers, leaf skeletonisers and lead "distorters" (psyllids, galls), with leaf chewers causing the most damage, up to 30% over summer, and dieback trees suffering more damage than healthy trees.	**Study type**	Reference vs Control (2)
	Control sample units	3 (4)
	Impact/treatment sample units	2 (2)
	Potential for bias weighting	Psedoreplication?

Synopsis	Critical appraisal	
Dieback trees generally had more epicormic growth (juvenile leaves), thinner canopies and more dead branches than healthy trees. Dieback trees had a higher concentration of foliar nutrients (N, P, K) than healthy trees, consistent with young (epicormic) growth generally having higher proportions of these nutrients than mature foliage. There was an opposite trend for soil nutrient between dieback and healthy trees. The authors proposed that production of epicormic growth favoured by insects could result in pest outbreaks, resulting in repeated defoliation events leading to depletion of carbohydrate reserves and dieback. The authors investigated long-term rainfall patters to test for White's (1969) stress index, with the study trees experiencing climatic water stress in the years when increasing dieback was first being identified.	**Potential for bias assessment**	
Leseberg et al. 2014 Leseberg et al. (2014) monitored Bell miner behaviour over 5 months at three sites across their range: south-east Queensland, central NSW, and Melbourne, Victoria. The understorey within Bell miner colonies in Queensland and NSW was dense undergrowth of either lantana or native shrubs, but "patchy" in Victoria, with a more open understorey outside the colonies. Assessments were carried out along transects from within the colony to up to 375 m from the colony edge. Bell miners occupied discrete, relatively stable geographical locations within defined boundaries, at least over the 5-month period of this study. Within these colonies give regular 'tink' calls and aggressively exclude other avian species. There was a significant reduction in avian richness and abundance within these defined colonies of bird species that occupy the same niche as Bell miners (e.g., potted pardalotes, white-naped honeyeaters), but no effect on understorey-dwelling species. This negative effect was restricted to the defined colony, with avian richness and abundance significantly increasing (3- to 5-fold) in the absence of Bell miners, immediately outside the defined colony. There was a strong negative influence of Bell miner presence on other avian competitors.	**Study type**	Gradient (3)
	Control sample units	3 (3)
	Impact/treatment sample units	3 (3)
	Potential for bias weighting	
	Potential for bias assessment	
Loyn et al. 1983 Loyn et al. (1983) removed Bell miners from a site in Olinda State Forest, near Melbourne, Victoria—which exhibited severe defoliation and dieback attributed to psyllids (*Glycaspis* spp.)—to monitor the effect on other avian species, psyllid numbers and tree health. They also monitored bird and psyllid activity at a 'healthy control' site (no Bell miners, no psyllids) and a 'psyllid-infested' site (no Bell miners, psyllids present). Prior to removal, Bell miners constituted 64% of birds observed at the Bell miner site, with the remainder mostly understorey species. Bell miners did not re-colonise the site, which was subsequently invaded by small flocks of insectivorous birds that fed on psyllids at a greater rate than the Bell miners had previously. For example, Bell miners consumed psyllids at a rate of 12 per minute, while five of the newly invading birds (including striated thornbills, white-napped honeyeaters, spotted	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
pardalotes and crimson rosellas) each consumed 25 psyllids per minute. By multiplying feeding rates by abundance of each bird species, the 'consumption rate' of Bell miners was 280 psyllids or lerps per minute under Bell miner colonisation compared to 650 psyllids or lerps per minute after Bell miner removal. Thus, the greater avian diversity consumed significantly more psyllids and lerps than Bell miners alone, ultimately "controlling" the insect outbreak. Consequently, the numbers of psyllids (counts of lerps on fallen leaves) dropped rapidly after Bell miner removal, virtually to zero within several months. There was no corresponding dramatic reduction in psyllids at the 'psyllid-infested' site, although psyllid numbers fluctuated, and few psyllids were recorded at the 'healthy control' site at any time. Six months after Bell miner removal, tree health "improved", based on an increase in epicormic flush that was not seen at the other sites.		
McDonald et al. 2002	**Study type**	Reference vs Impact (2)
McDonald et al. (2002) conducted controlled burns and manual weed removal, and combinations of these, in degraded Blue Gum High Forest in Sydney, NSW, which had a thinning canopy of eucalypts and a mid-storey dominated by a high density of exotic shrubs (including lantana and privet), with the aim of restoring native vegetation. Fire had been excluded from the site for over five decades, and there was negligible eucalypt recruitment. Five years after treatment, a diverse native flora regenerated across all treatments, indicating an intact soil seed bank. Native sclerophyll shrubs regenerated better following fire compared to manual weed removal. The authors provide anecdotal comments regarding degradation in Cumberland State Forest in NSW, and that there are "disproportionate numbers of Bell miners… possibly due to excessive lantana in the understorey." Study provides evidence of fire and mechanical removal of dense weedy understorey (lantana) can result in a return to a multi-layered native vegetation cover. Provided anecdotal evidence regarding Bell miners and understorey density.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	
Moore 1962	**Study type**	After impact (1)
Moore (1962) investigated the causes of dieback in *E. saligna* forests in over 150 sites across a broad geographic area in NSW (central coast, northern tablelands, north coast) during 1949 to 1959. Large numbers of *Glycaspis* psyllids were observed on a range of *Eucalyptus* species in areas identified with dieback ("debilitation and death"). Furthermore, Bell miners occurred in all areas where large numbers of psyllids were observed. *Thus, there was a strong association between Bell miner presence and psyllid abundance.* Foliage of eucalypts heavily attacked by *Glycaspis* spp. gradually becomes reddish-purple, the colour deepening over winter, and then prematurely shedding, with epicormic growth then common. Severe defoliation by *Glycaspis* spp. over several years predisposes trees to attack by other insects, including *Amasa truncata* (ambrosia beetle). *Glycaspis* spp. can have up to seven generations per year, and complete a generation within one month over summer. Egg laying preference by females	**Control sample units**	0 (0)
	Impact/treatment sample units	6 (3)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
along main veins indicates a favourable association with stronger sap flow. Moist conditions favour survival, with large populations observed following high rainfall years. Affected sites were determined to be of poor site quality, resulting in poor drainage during wet years. Parasites perform effectively only during dry weather conditions, and moist conditions favour *Glycaspis* spp.		
Nageli et al. 2016 Nageli et al. (2016) investigated the link between soil and foliar nutrients and crown health in Bell miner/BMAD-affected sites in northern NSW. Visual observations and leaf sampling revealed very few psyllids present, but an abundance of larvae of concealer moths and feeding damage. They propose that the continued drought experienced prior to and during the study adversely affected psyllid populations. However, the presence of Bell miners in these Bell miner/BMAD-affected sites and association with concealer moths indicate that Bell miners were feeding on the concealer moths; an observation not previously recorded. There was a negative association between “other” herbivorous insects and tree health at these BMAD sites.	**Study type**	Reference vs Control (2)
	Control sample units	5 (3)
	Impact/treatment sample units	5 (3)
	Potential for bias weighting	
	Potential for bias assessment	
Old et al. 1990 Old et al. (1990) investigated the effects of drought and defoliation on the susceptibility of eucalypts to canker fungi in glass-house trials and mature trees dry sclerophyll woodland in the southern tablelands of NSW. Plants were inoculated with canker fungi following: seedlings being subject to reduced water regimes and artificial defoliation; saplings being subject to artificial defoliation; and mature trees subject to almost complete defoliation by insects, matched to health trees. Artificial defoliation of seedlings and saplings, and severe insect defoliation of mature native trees, resulted in increased canker development of *Endothia gyrosa* and *Botryospaheria ribis.* Defoliation of both planted saplings and native trees resulted in a significant reduction in soluble and stored carbohydrates compared to non-defoliated (healthy) trees, and this persisted for at least one year (when the trial ended) for the trees, suggesting a “chronic depletion of the tree’s energy reserves”. Drought stress had no impact on the susceptibility of seedlings to canker fungi. The authors suggested that these canker fungi may play an important role in tree dieback following repeated sever defoliation by insects.	**Study type**	Reference vs Impact (2)
	Control sample units	2 (3)
	Impact/treatment sample units	2 (2)
	Potential for bias weighting	
	Potential for bias assessment	
Osunkoya and Perret 2011 *In progress*	**Study type**	
	Control sample units	

Synopsis	Critical appraisal	
	Impact/treatment sample units	
	Potential for bias weighting	
	Potential for bias assessment	
Pearce et al. 1995 Pearce et al. (1995) monitored bird abundance at Yellingbo State Nature Reserve, Victoria, to examine the competitive relationship between Bell miners and Helmeted Honeyeaters (*Lichenostomus melanops cassidix*) in an area where the former had been forcibly removed (culled) from parts of the reserve. Of 632 sites sampled, Bell miners occupied 169 and had been removed from 72. Sites with Bell miners were characterised by high levels of eucalypt dieback, sparse canopy cover and proximity to dense shrubs. Following removal of Bell miners, Helmeted Honeyeaters immediately visited vacated sites, eventually establishing new territories in 13 such sites. The results suggest that Helmeted Honeyeaters are actively excluded from certain sites by Bell miners.	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Poiani et al. 1990 Poiani et al. (1990) monitored the abundance of Bell miners, other avian competitors and other avian non-competitors, for seven years in a forest in Healesville, Victoria, which Bell miners have been gradually invading. As Bell miners increased in abundance, the abundance of competitive bird species (honeyeaters) decreased, but this difference was only significant ($P < 0.05$) over the summer months. Spatial transects out from Bell miner colonies showed an increase in abundance of competitors (honeyeaters) with distance from the Bell miner colony, but again this was not significant. Non-competitors did not seem to be affected by increasing Bell miner abundance. Thus, this study shows a correlation between a decrease in competitor (honeyeater) abundance following an invasion (increase) of Bell miners over a 7-year period.	**Study type**	Before vs After (2)
	Control sample units	0 (0)
	Impact/treatment sample units	1 (2)
	Potential for bias weighting	
	Potential for bias assessment	
Rose 1997 Rose (1997) assessed basal area and density of *Pittosporum undulatum* in bushland sites on urban edges, investigating the effect of different ages of invasion (assumed from the age of the development on the urban edge) and compared to similar sites but remote from urban influence. Mean basal area and density of *P. undulatum* was significantly greater in older, longer invaded sites, and also greater at the urban edge (assumed to be the initiation of invasion) compared to further into the bush. Interior	**Study type**	Reference vs. Impact (2)
	Control sample units	3 (3)
	Impact/treatment sample units	12 (3)

Synopsis	Critical appraisal	
sites remote from urban influence had no or minimal lantana. Human disturbance was positively correlated with basal area of *P. undulatum,* thus appearing to promote invasion and establishment, while evidence of fire was negatively correlated. Areas longer invaded had a greater size and density of P. undulatum, resulting in a denser understorey.	**Potential for bias weighting**	nil
	Potential for bias assessment	
Shipman 2006	**Study type**	Reference vs Impact (2)
Shipman (2006) monitored regeneration in a BMAD affected forest in Donaldson State Forest following three treatments to remove understorey vegetation, primarily lantana: (1) fire, (2) fire and mechanical, and (3) fire and herbicide. Initial lantana cover averaged 70% to 95% in the forest. Regeneration of canopy eucalypt species was poor and inconsistent (patchy) across the three treatments. Crown health at the sites was very poor, due to prolonged psyllid attack over many years, and this may have affected seed production. Prolific regeneration of other species following fire may also have inhibited eucalypt regeneration. Quoted another study at the site that fire and mechanical removal of lantana significantly reduced bell miner numbers, but 50% (Mews 2006). Couldn't find exact timeframe after fire that assessments were made.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	Initial variability among treatment plots
	Potential for bias assessment	0.5
Smith 1985	**Study type**	Reference vs Impact (2)
Smith (1985) conducted a bird census (including Bell miners) in mature eucalypt forest (unlogged) and regenerating forest (10–15 years after intensive logging) near Bega, southern NSW, comparing forests on ridges and in gullies. Overall bird abundance (number of species) was greater in gullies compared to ridges. There was no different in the total number of species between regenerating (logged) and mature (unlogged) forest located in gullies, but a significant difference between regenerating and mature forest located on ridges, with 20% fewer species in regenerating forests on ridges compared to mature forest on ridges. In gullies, although the number of species between regenerating and mature forests did not differ, the composition of bird species changed following logging: species of birds that generally feed, nest or shelter in dense vegetation were more abundant in the regenerating forest than the mature forest, including Bell miners. These were also generally birds that inhabit gullies, compared to ridges. Thus, Bell miners became more abundant in regenerating forest, ten to fifteen years following logging, compared to mature forest. Note that retained mature trees in the logged forest were a source of nest hollows and food for many bird species that rely on hollows or mature trees.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	
Smith and Robertson 1978	**Study type**	
Smith and Robertson (1978) observed Bell miner activity and behaviour over a two-year period in a population in Bundoora, Victoria. Bell miners occupied an area of forest with an understorey of mainly	**Control sample units**	

Synopsis	Critical appraisal	
exotic scrub, but not adjacent forest with an open grassy ground-cover. They defended an area that coincided with their foraging area. Nesting height averaged 2.5 m, and generally in shrubs, including exotic and native species. Total breeding success was low (23%), and mortality was high in fledglings (60%). Over 30 other avian species were recorded entering areas occupied by Bell miners; 26 of these species were attacked, often continuously and by multiple Bell miners until they left the area, and all were species that occupy the same niche as Bell miners – between the understorey and the canopy. Other bird species entering colonies and restricting activity to the understorey were not hassled. Thus, these observations provide strong evidence that Bell miners aggressively defend their territory from other avian species.	**Impact/treatment sample units**	
	Potential for bias weighting	
	Potential for bias assessment	
Somerville et al. 2011 Somerville et al. (2011) removed lantana from degraded forest in northern NSW to monitor the impact on native regeneration, Bell miners and tree health. The forest had been previously logged and grazed, with stopped in 1980. By the 1990s Bell miners had established "large persistent colonies", purportedly feeding on psyllids in eucalypt crowns, with "BMAD evident and increasing". In 2000, a large area of the forest was infested with lantana, with densities ranging from 25–80%; BMAD affected 80% of the forests, and was always associated with dense lantana and high numbers of Bell miners. Lantana removal began in 2006, progressively moving through the worst affected areas (~300 ha), with a combination of physical and chemical control, including follow-up treatments of regenerating lantana, effective in controlling lantana. In areas with sparse lantana and good canopy density, native regeneration was able to outcompete lantana; in degraded areas with dense lantana, repeated treatments were necessary until the mid-storey developed to shade-out and outcompete the lantana. Prior to lantana removal (2005), Bell miners were found across the forest, with trees "subject to psyllid attack and producing epicormic growth…until they finally died". By 2011, Bell miners had completely moved out of three sites within the lantana-cleared forest, but remained in two sites, both of which had adjacent lantana-infested forest. An influx of other avian species was observed in treated areas, compared to areas infested with lantana and Bell miners. While some younger and more damaged trees died following lantana removal, most trees have recovered with a healthy crown. Bell miners were consistently associated with dense lantana understorey, and removal of the lantana understorey resulted in a reduction and final absence of Bell miners at most treated sites.	**Study type**	Before vs After (no control) (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	
Steinbauer et al. 2014 Steinbauer et al. (2015) assessed leaf quality straits (including foliar nitrogen), psyllid abundance, parasitoids abundance and psyllid parasitism, Bell miner abundance and epicormic growth (as	**Study type**	Reference vs Impact (2)
	Control sample units	3 (3)

Synopsis	Critical appraisal	
symptom of BMAD) at four localities in northern NSW. Sites chosen were either affected by BMAD (canopy dieback, established Bell miner colonies, dense understoreys of natives and invasive weeds) or “at risk” (low levels of dieback, newly established or adjacent Bell miner colonies, and a dense understorey). A control, with no Bell miners, was assessed at three of the localities. Although there was a significant positive relationship between number of Bell miners in a plot and number of lerps (all species) per leaf — the abundance of lerps on leaves was higher in plots with Bell miners — this was not universal, with one location not following the same trend. A similar relationship was seen when comparing *Glycaspis* spp. only. The abundance of *Psyllaephagus* parasitoids was positively correlated with the abundance of lerps, and this was highly significant. But there was no relationship between lerp abundance and percentage parasitism, likely due to hyperparasitism, with an increasing abundance of hyperparasitoids found with increasing abundance of *Psyllaephagus* parasitoids. Younger leaves had higher nitrogen contents, and Bell miner abundance and foliar nitrogen were positively correlated with lerp abundance. *Glycaspis* preferred recently expanded, younger leaves, but was not associated with discolouration or defoliation, while *Cardiaspina* preferred mature, older leaves, and attack resulted in necrosis and defoliation. The authors concluded that high quality epicormic foliage, generated following defoliation, favours populations of *Glycaspis*¸ and that this potentially creates psyllid hotspots that favour Bell miners.	**Impact/treatment sample units**	4 (3)
	Potential for bias weighting	
	Potential for bias assessment	
Stewart 1990 Stewart (1990) compared avifaunal communities at two eucalypt forest sites in Brisbane Forest Park, south-east Queensland, one with bell miners the other with no bell miners. Foliage gleaning birds were mostly missing from the site with bell miners, due to interspecific aggression; bell miners were observed attacking 27 bird species. The result was that bell miners obtained virtual sole occupancy of the canopy stratum. The understorey at the bell miner site, dominated by lantana, was denser than at the site without bell miners.	**Study type**	Reference vs Impact (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Stone et al 1995 Stone et al. (1995) conducted a qualitative analysis of data collected by field staff who were asked to assess a range of site, stand-level and tree-level characteristic within known “dieback” sites in State Forests across central and northern NSW. Data collected included topography, floristic composition of the overstorey and understorey, levels of crown dieback and psyllid attack, and Bell miner counts. The	**Study type**	After impact only (1)
	Control sample units	0 (0)
	Impact/treatment sample units	8 (3)

<table>
<tr><th>Synopsis</th><th colspan="2">Critical appraisal</th></tr>
<tr><td rowspan="2">survey identified over 2000 ha of moist hardwood forest as having symptoms of dieback, with generally isolated patches affected, from 1 ha up to 100 ha. Many eucalypt species with dieback also had high numbers of psyllid attack, but this was not consistent, with some species having high psyllid and no dieback and visa versa. The majority of plots identified with dieback had a history of logging (97%), Bell miner colonies (93%), a medium or dense understorey (90%) and occurred on upper slopes or ridgetops (62%). Lantana was present in 36% of plots, and although Bell miners were present in each of these, there was no relation between lantana and Bell miner colony size (abundance). There was no apparent relationship between the presence of lantana and the size of Bell miner colonies, nor the presence of lantana and severity of dieback symptoms or psyllid attack. Thus, there was a very strong association between dense understorey and the presence of Bell miners in dieback sites, but no indication of a density-dependant relationship.</td><td>Potential for bias weighting</td><td>Qualitative analysis</td></tr>
<tr><td>Potential for bias assessment</td><td></td></tr>
<tr><td rowspan="5">Stone 2005
Stone (2005) identified factors and processes associated with BMAD based on assessments of floristic composition, stand structure, canopy condition, overstorey and understory density, Bell miner density and soil characteristics, in 24 plots across a broad range of forest types in northern NSW. Eucalypt stands that support Bell miners tended to have a dense shrubby understorey and were relatively fertile. There was a negative correlation (r = -0.75, P <0.001) between mean crown condition and Bell miner density, indicating a density-dependant relationship between Bell miners and herbivorous insects, and hence tree health (insect damaged foliage). A key characteristic of eucalypt stands susceptible to Bell miner colonisation was a dense understorey.</td><td>Study type</td><td>Reference vs Impact (2)</td></tr>
<tr><td>Control sample units</td><td>1 (2)</td></tr>
<tr><td>Impact/treatment sample units</td><td>1 (0)</td></tr>
<tr><td>Potential for bias weighting</td><td>nil</td></tr>
<tr><td>Potential for bias assessment</td><td></td></tr>
<tr><td rowspan="5">Stone and Simpson 2006
Stone and Simpson (2006) assessed a range of leaf, tree and plot-scale parameters in six sites in an E. saligna forest in Sydney, NSW, all with different floristic composition, structure and crown condition, based on past management (including fire history, recreation use and topography). Only one site had an active Bell miner colony, and this was also the only site with Glycaspis psyllids. It also had the poorest crown condition score, with evidence trees were dying, and a dense mesic understorey dominated by exotic species including lantana. Other sites had lantana, but at a much lower density due to manual weed removal. Crown condition at the other sites was either good or moderate (significantly healthier than the Bell miner site). Phytophthora cinnamomic was found in soils at all sites except one, including the Bell miner site.</td><td>Study type</td><td>Reference vs Impact (2)</td></tr>
<tr><td>Control sample units</td><td>1 (2)</td></tr>
<tr><td>Impact/treatment sample units</td><td>1 (0)</td></tr>
<tr><td>Potential for bias weighting</td><td>Not replicated; only single site with Bell miners and psyllids</td></tr>
<tr><td>Potential for bias assessment</td><td></td></tr>
<tr><td></td><td>Study type</td><td>Reference vs Impact (2)</td></tr>
</table>

Synopsis	Critical appraisal	
Stone et al. 2008 Stone et al. (2008) assessed forest attributes — including canopy health and stand structure — to identify features associated with Bell miners on the central coast of NSW, based on 130 plots across a 12,800 ha study area (Jilliby Catchment Study Area). Thirty-seven (37) plots were colonised by Bell miners out of a total of 130 plots. The presence of Bell miners was significantly (*P* < 0.001) associated with poor canopy health, and there was a strong association of poor canopy health (sparse canopy) and a dense lower-mid-storey (*P* < 0.002) with the presence of Bell miners. Conversely, Bell miners there was a negative association between Bell miners and a sparse lower-midstorery or the presence of an established upper-mid-storey. Bell miner abundance (presence) was strongly associated with a dense lower-mid-storey (understory) and eucalypt tree health.	**Control sample units**	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	nil
	Potential for bias assessment	
Stone et al. 2010 Stone et al. (2010) conducted shadehouse experiments with *E. dunnii* to determine whether intermittent waterlogging increased susceptibility to the psyllid *Creiis lituratus* compared to drought or normal water regimes. Waterlogged seedlings had significantly (*P* < 0.001) more psyllid eggs and nymphs compared to the other treatments. The nymphal instars settled on fully expanded young leaves to feed. Feeding resulted in localised chlorosis then reddish-purple discolouration, finally becoming necrotic. Although waterlogged plants had a greater number of severely damaged leaves, this was not statistically different from the other treatments. *Creiis lituratus* clearly had a preference for waterlogged plants. The chlorophyll fluorescence parameter measured (F_v/F_m) was significantly lower in waterlogged plants, indicative of physiological stress. The analysis of foliar amino acid concentrations provided no clear picture to separate the treatments.	**Study type**	Reference vs Impact (2)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	Creiis psyllid in young dunnii quite a different beast to Glycaspis or Cardiaspina
	Potential for bias assessment	
Walters et al. 2005 Walters et al. (2005) measured the variation in carbohydrate reserves and sprouting ability of *Eucalyptus obliqua* seedlings to provide information regarding sprouting ability and survival following damage events (such as fire, grazing). Seedlings were cut above the lignotuber to simulate grazing or fire and recovery/re-sprouting compared between provenances with typically large lignotubers and those with typically small lignotubers. Provenances with larger lignotubers had larger root and lignotuber biomass, higher concentrations of carbohydrate reserves and thus larger pools of carbohydrate reserves. Such provenances produced a significantly greater number of sprouts and a greater total biomass following clipping compared to provenances with small lignotubers. The implication is that seedlings with small lignotubers are less likely to survive multiple defoliation (fire, browsing) events.	**Study type**	Gradient (3)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	

Synopsis	Critical appraisal	
Ward and Neumann 1982 Ward and Neumann (1982) conducted aerial and ground surveys of forested areas in the Dandenong Ranges, Victoria, to map dieback and determine its cause. In 1978, 7.4% of the area was dieback-affected, and this increased to 9.4% in 1982, including an expansion of areas mapped in 1978. A wide range of *Eucalyptus* species were affected. They found no evidence to suggest dieback was associated with any particular "forest land-use". The authors concluded that the dieback appeared to be caused by *Glycaspis* spp. psyllids—which caused premature defoliation—with significantly more psyllids on trees from dieback affected forests than from trees in 'healthy' forests. Most psyllids were feeding on young succulent leaves. A definitive reason for such large populations of psyllids was not determined, but may have been stress from winter waterlogging followed by protracted drought. Parasitic insects did not play a significant role in controlling pest populations. Bell miners, in contrast, were found to be associated with forests supporting high levels of psyllids.	**Study type**	After impact (1)
	Control sample units	0 (0)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	
Wills et al. 2004 Wills et al. (2004) extended the experiment of Abbott et al. (1993) with *E. marginata* for a further 15 years, comparing annual complete defoliation with no defoliation. Undefoliated saplings were 3.6 times larger (stem diameter) than completely defoliated trees. No plants died, despite 15 years of repeated defoliation. However, almost half of the defoliated trees had died back to below 30 cm above ground.	**Study type**	BACI (4)
	Control sample units	1 (2)
	Impact/treatment sample units	1 (0)
	Potential for bias weighting	
	Potential for bias assessment	